Rio Chama Reservoir Operations Pilot Overview and Transmittal Report

San Juan-Chama Project, New Mexico
Upper Colorado Basin Region

U.S. Department of the Interior

July 2022

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

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.

Disclaimer. To provide a foundation for future analyses and potential paths forward for adaptive management processes in the Rio Chama watershed, this transmittal report summarizes the results from Reclamation-funded studies at the University of New Mexico. These studies are attached in full to this transmittal report. Each of these reports underwent established quality assurance and controls from the University of New Mexico. Reclamation has not independently verified these results.

Cover photo. View of Rio Chama looking upstream at Big Eddy Boat Takeout (Reclamation).

Acronyms and Abbreviations

BLM	Bureau of Land Management
cfs	cubic feet per second
EDWA	Emergency Drought Water Agreement
ESA	Endangered Species Act
IFIM	Instream Flow Incremental Method
mg/l	milligrams per liter
mm	millimeters
MRGCD	Middle Rio Grande Conservancy District
NMISC	New Mexico Interstate Stream Commission
RCFP	Rio Chama Flow Project
Reclamation	Bureau of Reclamation
RM	river mile
SJCP	San Juan-Chama Project
UNM	University of New Mexico
URGSiM	Upper Rio Grande PowerSim Operations Model
URGWOM	Upper Rio Grande Water Operations Model
USACE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
Utton Center	Utton Transboundary Resources Center

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Attachments

- **Ecosystem Report:** Summary of Rio Chama Ecosystem Technical Studies (Harvey 2022)
- **Economic Report:** An Economic Evaluation of Peak Flow Management on the Rio Chama (Chermak and Stradling 2022)
- **Legal Report:** The Law of the Rio Chama (Utton Transboundary Resources Center [Utton] 2022)

Summary

Study Purpose

The overall objective for this pilot project was to provide a foundation for examining operational flexibilities in the Rio Chama between Heron Dam and Abiquiu Reservoir. The Bureau of Reclamation's (Reclamation) Rio Chama Reservoir Operations Pilot Project funded three University of New Mexico (UNM) studies to examine aspects of Rio Chama operations within the Wild and Scenic reach of the Rio Chama without adversely affecting downstream water users. These UNM Reports are attached to this Reclamation Transmittal Report.

- Summary of Rio Chama Ecosystem Technical Studies (Harvey 2022)
- An Economic Evaluation of Peak Flow Management on the Rio Chama (Chermak and Stradling 2022)
- The Law of the Rio Chama (Utton Transboundary Resources Center [Utton Center], 2022)

Watershed and Infrastructure

The Rio Chama watershed in southern Colorado and northwestern New Mexico plays a pivotal role in the Rio Grande water supply and delivery system. The Rio Chama is the primary tributary to the upper Rio Grande Basin, supplying about 200,000 acre feet of runoff, annually. El Vado (1935), Abiquiu (1963) and Heron (1974) Dams along the Rio Chama capture the abundance of spring runoff to regulate water supplies throughout the year. Reclamation's San-Juan Chama Project (SCJP) imports another 96,000 acre-feet of water from the San Juan River Basin through a series of diversion dams and tunnels under the Continental Divide into the Rio Chama. These reservoirs provide water supplies to Reclamation's Middle Rio Grande Project while Abiquiu Reservoir provides flood protection for central New Mexico. Within the watershed, Rio Chama supplies water to irrigate over 25,000 acres, hosts a recreation economy that the region depends on, provides hydropower, and supports a novel ecosystem that has adjusted physically to the changes in hydrology and sediment supply since 1935.

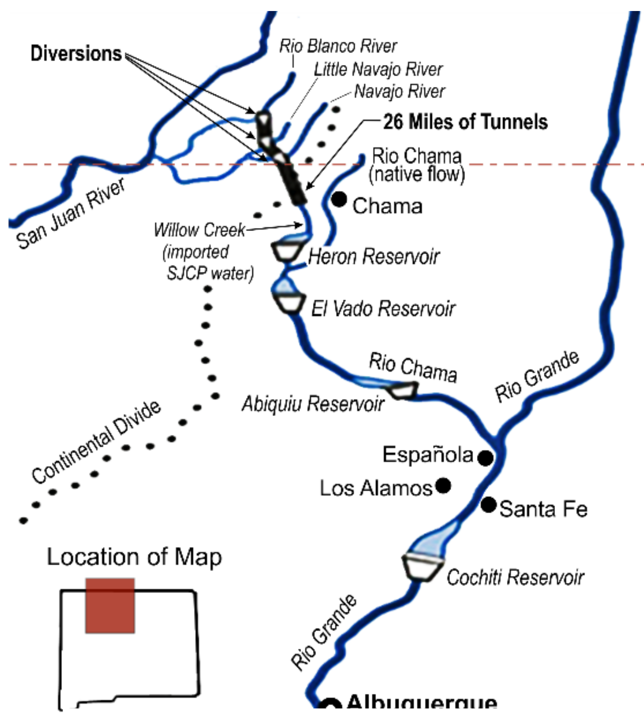

Figure ES-1. Location map (southern Colorado and northern New Mexico).

With the infrastructure and imported water changes, the river has transformed from high spring flood flows with little water during the rest of the year to with much lower flood flows and water delivered throughout the year to meet a complex set of administrative mandates. Further, there is more water in the river today than there was historically from the SCJP trans-basin imported water flows—a unique situation in the Western United States.

Problems and Needs

Issues in the watershed include the continually evolving physical river characteristics from flows and sediment transport, ecosystem responses to these physical changes, water quality concerns, and the ability to adapt to climate change. Climate change modeling projects that the SJCP imported flows will decrease by about 25 percent on average (Reclamation et al. 2013). Flow timing is also projected to change in the Colorado headwaters, the Rio Chama basin, and the San Juan-Chama Project tributaries and flow volumes could reduce by 16 to 28 percent (Reclamation et al. 2013).

Opportunities

Water is not withdrawn in the 35-mile-long reach of the Rio Chama between El Vado Dam and Abiquiu Dam, including 24.6 miles of a congressionally designated Wild and Scenic River reach. Therefore, 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. Moreover, there is a history of successful flow management in this river reach. For example, since 1986, Rio Chama flow management has been modified to provide rafting and some additional environmental benefits.

Operational and Management Objectives

Over the last decade, Reclamation has worked with the Rio Chama Flow Project (RCRP) to look at potential operational and management changes on the Rio Chama. The RCFP works with local, State, and Federal partners to promote cooperative, adaptive management to improve the economic and environmental performance of—and increased satisfaction of all parties with—river operations. Water operations based on sound multi-disciplinary science and robust and sustainable policy within an Adaptive Management framework could help address the watershed's challenges in water rights administration, water quality impairment, water use efficiencies and watershed conservation. Restoring the river to pre-El Vado Dam (1935) conditions is not an RCFP objective. Rather, operational improvements within the constraints imposed by the available flows and below-dam sediment supply and transport could improve the river and novel ecosystem that has developed over the last century.

UNM Recommended Future Analyses and Studies

The understanding of the system gained through these study efforts and the identification of operational, legal, and institutional constraints could be enhanced through additional studies and modeling to further evaluate operational flexibilities and the impacts of changes in flows. River erosion and physical changes, particularly near roads and structures could be monitored to determine erosion rates and any risks to streamside infrastructure.

Further research at the established research sites could analyze changes since 2011 and 2013. Non-market values, sediment, water temperatures, flow pulses, habitat, macroinvertebrates and fish could be further studied. Further research for recreation visitation, ecosystem modeling, and small hydropower economics could help refine economic analyses to analyze tradeoffs for potential actions within the Rio Chama.

Rio Chama operations could explore legal flexibilities to avoid releasing carryover storage by December 31 and thus continue to release ecological flows after fall fish spawning between January and April as well as to support winter bald eagle foraging habitat. Peak flows could redistribute tributary-supplied sediment, transport sediment, form in-channel habitat, and improve existing habitat for fish spawning and macroinvertebrates upstream of the Rio Gallina's confluence with the Rio Chama and could develop a more dynamic and complex river system that improves both in-channel and floodplain habitats for the benefit of fish, macroinvertebrates, and riparian vegetation downstream of El Vado Dam.

Flow schedules could be optimized to allow adding significant regional economic value with more short-term flows for hydropower peak generation and water-based recreation (fishing and boating) and could also improve environmental flows without adversely affecting downstream water users as noted in Utton 2022 Section VII. *Finding Institutional Flexibility:*

> *Water management is an incredibly dynamic operating environment, especially in the American Southwest. Water managers face dramatically changing conditions from one water year to the next. They do so within, what is perceived as, a tightly constrained legal and regulatory environment. Nonetheless, over time New Mexico water managers have shown great imagination in developing new tools within existing legal authorities.*
>
> *The development of new water management tools does not occur overnight. At times it seems that New Mexico's water managers are able to respond remarkably quickly to new challenges. However, in the background of these apparently rapid responses there have always been pre-existing collections of information, positive working relationships, and conversations about new ideas that range from the embryonic to the full developed. New water management regimes are often the result of decades of discussion and contemplation.*
>
> *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.*

1. Background and Introduction

1.1. Reservoir Operations Pilot Program Transmittal Report

The Bureau of Reclamation's (Reclamation) Reservoir Operations Pilot Program helps Reclamation water managers find ways to expand flexibility of reservoir operations to improve Reclamation's ability to perform its mission. Under this Program, Reclamation funded three University of New Mexico (UNM) investigations as a basis to explore reservoir operational flexibility within the reservoirs in northwestern New Mexico, which provide water to Reclamation's Middle Rio Grande Project and flood protection for central New Mexico. These reports are provided as attachments to this Reclamation transmittal report.

- **Summary of Rio Chama Ecosystem Technical Studies (Harvey 2022).** Summarizes and integrates the findings of the Rio Chama Flow Project (RCFP) baseline and other studies to provide an understanding of how and why the current conditions in the Rio Chama developed as well as a roadmap to inform future scientific investigations that will both help sustain the novel ecosystem that has developed since El Vado Dam was constructed in 1935 and provide ecological improvements.
- **An Economic Evaluation of Peak Flow Management on the Rio Chama (Chermak and Stradling 2022).** Uses a system dynamics framework based on river hydrology to evaluate the potential effects of alternative scenarios and describe the economic trade-offs involved in each.
- **The Law of the Rio Chama (Utton Transboundary Resources Center [Utton] 2022).** Summarizes findings on the constraints of, and flexibilities inherent within, the Law of the River. This report draws from interconnected elements of the laws of the Rio Grande and the Colorado River.

1.2. Location and Operations

These Reservoir Operations Pilot Study reports from the University of New Mexico focus on the reach of Rio Chama between Heron Lake and Abiquiu Reservoirs in New Mexico. The Rio Chama enters the Rio Grande about 28 river miles (RM) below Abiquiu Reservoir (Figure 1). As part of the Colorado River Storage Project, the SJCP diverts water from the upper tributaries of the San Juan River, through the Continental Divide, and into the Rio Grande Basin. The three San Juan River contributing watersheds of the SJCP are: the Rio Blanco, the Little Navajo River, and the Navajo River. Once diverted under the Continental Divide, SJCP water is stored in Heron Reservoir on Willow Creek at its confluence with the Rio Chama immediately upstream of El Vado Reservoir. Below Heron Reservoir, the headwater flows of the Rio Chama are stored in El Vado Reservoir. At the downstream end of the project reach, streamflow is regulated by the U.S. Army Corps of Engineers (USACE) in Abiquiu Reservoir (Table 1). Between El Vado Dam and Abiquiu Reservoir, the Rio Chama conveys roughly 400,000 acre-feet of water per year, including 96,200 acre-feet (firm yield) of imported SJCP water, with negligible consumptive usage.

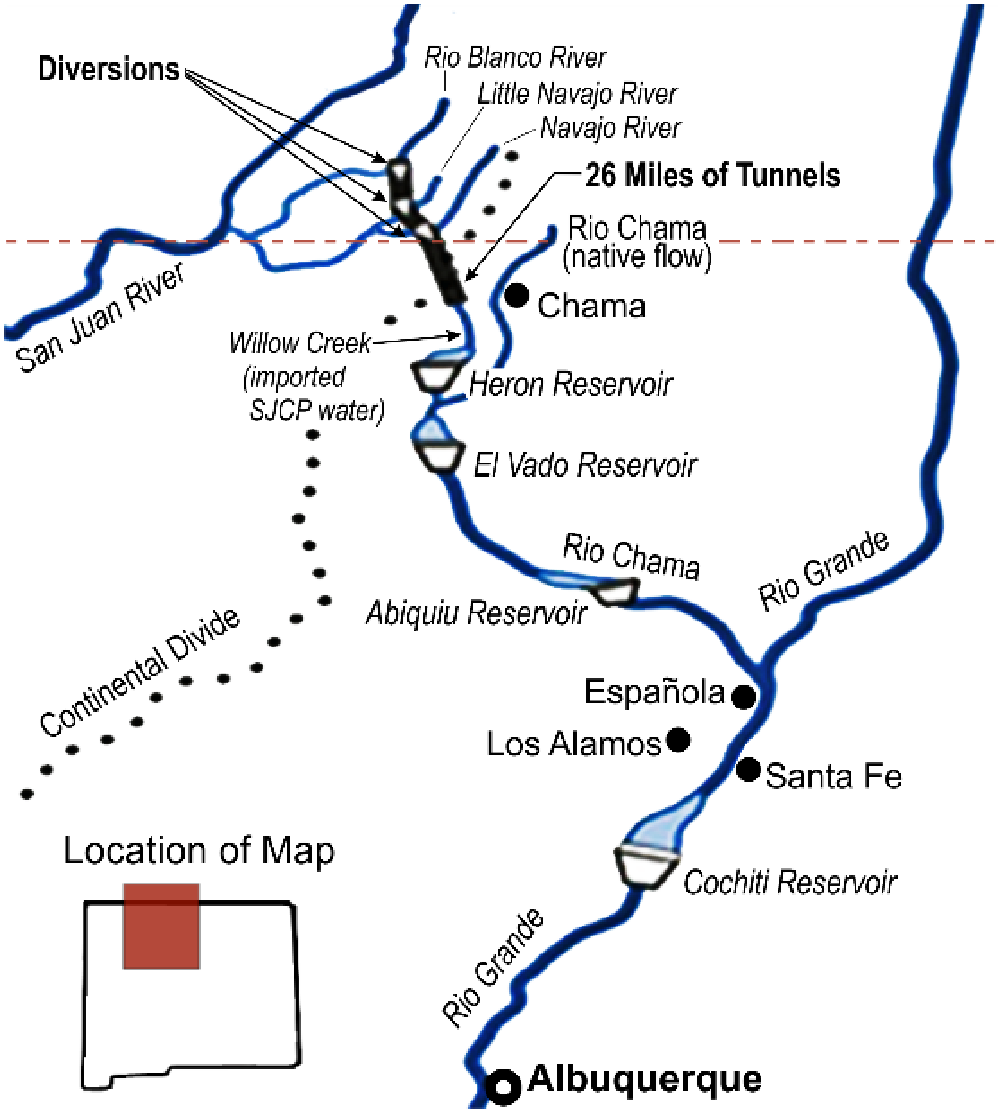

Figure 1. Location map for reservoirs and rivers in southern Colorado and Northern New Mexico.

Table 1. Rio Chama Reservoir Descriptions

	Heron Lake	**El Vado Reservoir**	**Abiquiu Reservoir**
Capacity	401,320 acre-feet	196,500 acre-feet	729,665 acre-feet
Purpose	Storage	Storage, hydropower	Flood control and storage for SJCP water
Supply	SJCP	SJCP and native flow	SJCP, Native flow, El Vado releases
Operator	Reclamation	Reclamation	U.S. Army Corps of Engineers
Storage Rights	Firm yield for SJCP	Middle Rio Grande Conservancy District Albuquerque	Albuquerque Bernalillo County Water Utility Authority (ABCWUA)

Covering over 3,000 square miles (over 8,100 square kilometers), this watershed extends into southern Colorado (Archuleta and Conejos counties), and Rio Arriba, Sandoval, and Taos counties in New Mexico (Figure 2). The watershed includes Ohkay Owingeh and Santa Clara Pueblos in the south, portions of the Jicarilla Apache Indian Nation in the north, as well as the towns of Vallecitos, El Rito, Abiquiu, Coyote, Canjilon, Cebolla, Canones, Tierra Amarilla, and Chama. All of these towns, reservations, reservoirs, forests, and tributaries are considered integral to the watershed ecosystem.

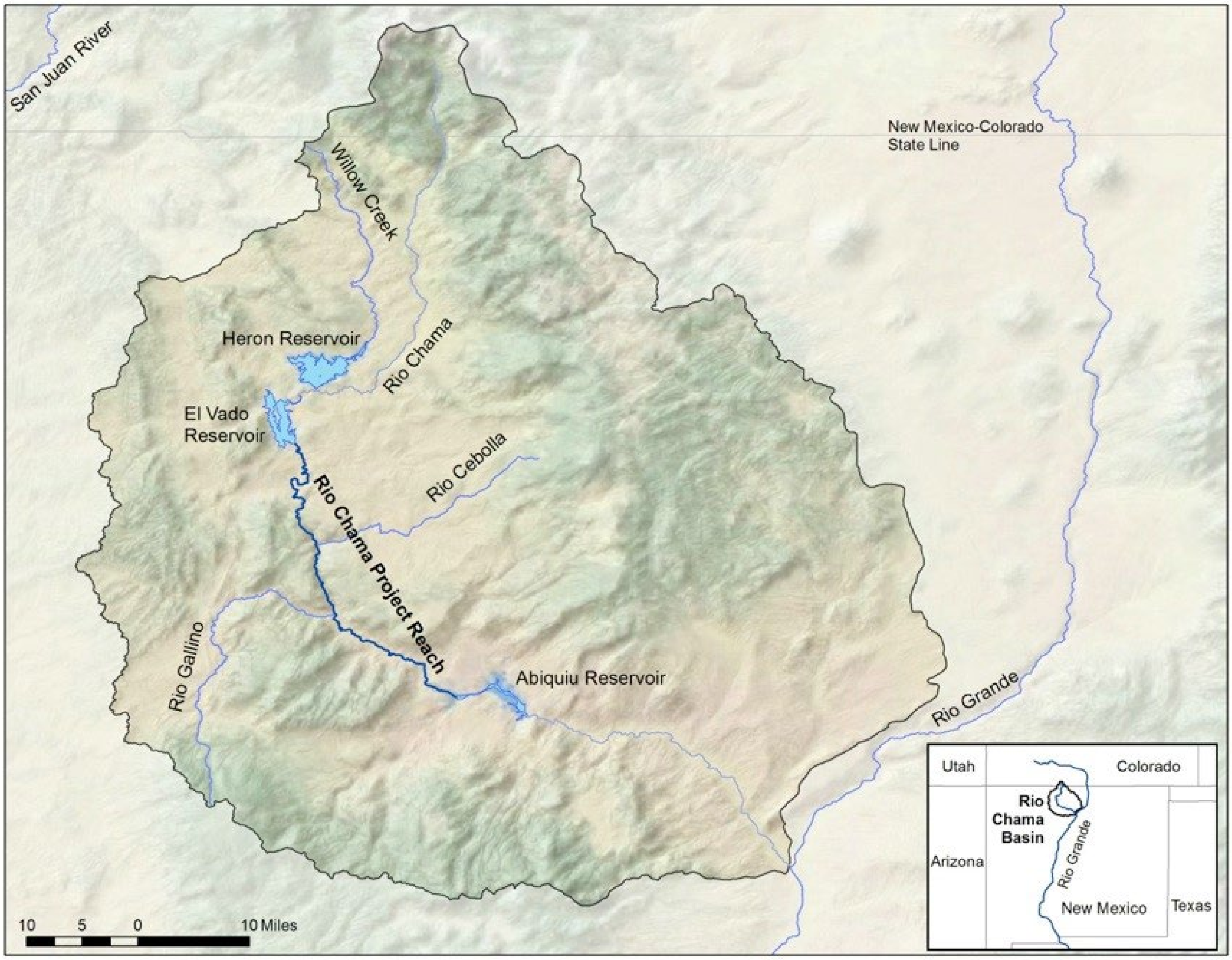

Figure 2. Rio Chama watershed and 34-mile long reach between El Vado and Abiquiu Reservoirs.

1.3. Rio Chama Flow Project

The RCFP is a long-term non-profit program and partnership initiative to involve Rio Chama water users, residents, and managers in collecting and understanding information on river flows and in creating alternative management scenarios that improve conditions for the river, the ecosystem and its water users. RCFP was created in 2010 to identify the optimal flows to enhance social and ecological benefits on the 31-mile stretch between El Vado and Abiquiu Reservoirs. The project implementation team is comprised of land and water management agencies (Reclamation, Bureau of Land Management [BLM], New Mexico Interstate Stream

Commission [NMISC], USACE, Middle Rio Grande Conservancy District [MRGCD], and the U.S. Forest Service [USFS]); local landowners; private environmental and engineering consultants; University of New Mexico's Engineering, Geography, and Law School faculty; and non-governmental conservation organizations (Trout Unlimited and Rio Grande Restoration).

The RCFP's intended outcome is improved economic and environmental performance of—and increased satisfaction of all parties with—river operations, by creating a collaborative process for determining annual water operations that is based on sound multi-disciplinary science and robust and sustainable policy within an adaptive management framework.

1.4. Previous Studies

The Rio Chama Management Plan for the Wild and Scenic designated reach was finalized by the USFS, BLM, and USACE in 1990. The Management Plan identifies meeting delivery requirements of Rio Chama water rights holders and SJCP contractors as the highest priority for flow management, followed by maintaining the aquatic ecosystem. As recommended in the Management Plan, an instream flow assessment was prepared, which highlighted four areas of concern: flow magnitudes at the appropriate time of the year, water temperature, sedimentation, and macroinvertebrate food base (Fogg et al., 1992).

Recent study compilation work by Reclamation's West Wide Climate Risk Assessment Team, as part of the development of the 2016 SECURE Report to Congress, points to the Rio Grande Basin as an epicenter of projected water shortages as a result of climate change. This decrease in available water, along with the projected changes in the spatial and temporal distribution of water, will lead to greatly increased challenges for the management of the Rio Chama, its reservoirs, and its novel ecosystem.

2. University of New Mexico Report Summaries

2.1. Ecosystem Report (Harvey 2022)

In the UNM *Summary of Rio Chama Ecosystem Technical Studies*, Harvey provides a literature synthesis and results from RCFP studies. See the Ecosystem Report Attachment. Harvey states that the ecosystem in this reach of the Rio Chama has changed over the last 85 years since El Vado Dam was constructed and water operations have focused on meeting downstream water demands. This post-dam ecosystem meets the definition of a novel ecosystem proposed by Morse et al. (2014), as it is based on infrastructure changes to the river, has crossed ecological thresholds, has altered species composition, and is a sustainable ecosystem.

Harvey affirms that sustaining and improving the Rio Chama novel ecosystem relies on understanding its origins from the changes in flow operations and sediment supply. He used a process-based, 4-level hierarchical framework to assess the riverine-floodplain ecosystem effects of dam operations over space and time to develop this understanding. The framework allows for clear assessment of physical and biological process linkages at a range of spatial and temporal scales, and the cascading effects of dams from first-order physical drivers (hydrology, water quality, sediment supply, ice processes) to second- order geomorphic (channel and floodplain morphology, hydraulics and sediment transport) and third-order (floodplain and aquatic vegetation, invertebrates, fish, birds and mammals) responses to fourth-order bio-geomorphic feedback processes.

2.1.1. Study Locations and Approach

Harvey 2022 provides study results for four specific study sites in the confined canyon section of the river selected for their alluvial nature—and thus their potential for adjustment as well as two study sites in the lower, less confined reach downstream of the Rio Gallina confluence.

As part of the RCFP, a system dynamics model was created to evaluate impacts of reservoir operations on various users and ecosystem components (Morrison, 2014 and Morrison and Stone, 2015a and b). This model was designed to link to the Upper Rio Grande PowerSim Operations Model (URGSiM), a monthly time-step operations model, which was used in the Upper Rio Grande Impact Assessment (Reclamation et al., 2013), part of Reclamation's West Wide Climate Risk Assessment. The Upper Rio Grande Water Operations Model (URGWOM) can also be used to evaluate reservoir operations and their constraints and flexibilities. URGWOM is a RiverWare model developed by an interagency team, including Reclamation, USACE, U.S. Geological Survey (USGS), and the NMISC.

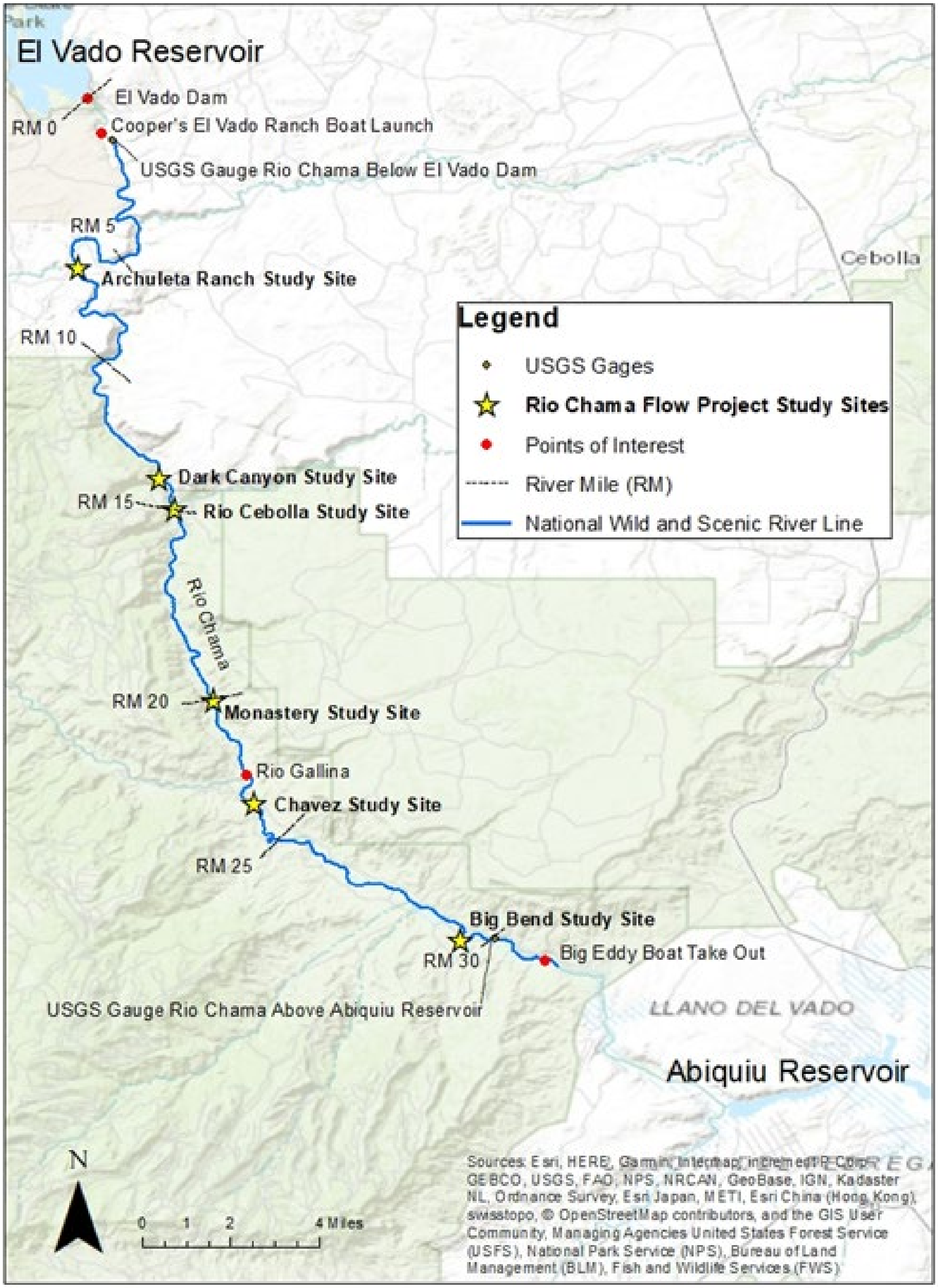

Figure 3. Locations of six Rio Chama Flow Project study sites in the Wild and Scenic reaches of the Rio Chama (RCFP). (Harvey 2022 Section 3.2.1. *Research Sites and Activities).*

2.1.2. Summary of Results

The UNM study (Harvey 2022) documents the model and previous studies analyses of Rio Chama system changes. This list highlights some of the changes that Harvey 2022 documents.

- **Physical system changes** include:
  - Peak flows are lower and annual and seasonal flow are less variable—reducing the frequency of remobilization of debris flow and deposits (Harvey 2022 Section 3.1.1. *Hydrology* and Section 3.1.2. *SJCP Diversions*). Reductions in peak flows since the dam was constructed have caused hydrological disconnection of the pre-dam floodplain throughout the Wild and Scenic reach (Harvey 2022 Section 3.3.1. *Floodplain and Aquatic Vegetation*).
  - The post-dam floodplain, formed as a result of channel narrowing (by 20 to 35 percent) due to bar-accretion and vegetation encroachment into the channel, is inundated by flows of 2,500 cubic feet per second (cfs). (Harvey 2022 Section 3.2.2. *Floodplain Morphology*).
  - Increased peak flows since 2009 along the Rio Chama have accelerated lateral erosion of pre-dam floodplain surfaces, as well as higher elevation pre-dam terraces that support Rocky Mountain juniper, cottonwood, oak, and box elder trees. Erosion of these surfaces by the river introduces large woody debris into the river, especially downstream of Rio Gallina. Bank-attached large woody debris can accelerate bank erosion downstream, thereby increasing the amount of woody debris that is added to the river (Harvey 2022 Section 3.4. *Fourth-order Impacts*).
  - The dam has 100 percent trap efficiency for sand and larger sediment sizes, so all geomorphically-significant sediment below the dam is supplied by tributaries, primarily in the form of debris flows during the monsoon season (Harvey 2022 Section 3.1.3. *Sediment Supply*). Gravels are mobilized at flows of about 3,000 cfs. Sand-sized material is entrained along the entire channel—even though coarser material (24 to 68 millimeters [mm]) may not be below the tributary confluences, which may explain why below the major tributary confluences frequently there is split-flow round gravel/cobble islands. (Harvey 2022 Section 3.2. *Hydraulics and Sediment Transport*). Debris flows in the tributaries contribute larger sediment (e.g., rocks) come from the tributaries. These occur about every 3 years.
  - Water quality concerns (turbidity, temperature, and chemistry) have increased (Harvey 2022 Section 3.1.4. *Water Quality*).
    - **Turbidity.** The accumulated sediment in El Vado Reservoir is at the level of the El Vado Dam power station inlet so he annual pass through the reservoir is probably on the order of the annual inflow, which is about 59 acre-feet/year (0.3 tons/acre/year). The average sediment concentration in the Rio Chama downstream of El Vado Dam of about 190 milligrams per liter (mg/l), almost twice the 100 mg/l the ecological impairment threshold set by the U.S. Environmental Protection Agency (Harvey 2022 Section 3.1.3.1. *Upstream Sediment Supply* and 3.1.4.1 *Turbidity*).

        - **Temperature.** The optimal range for brown trout juveniles and adults is between 12 degrees Celsius (° C) and 19° C. Brown trout are observed in the upper Rio Chama (RM 1 to RM 15), where summer water temperatures do not appear to limit the species. However, water temperatures as high as 25° C have been measured in late July at a flow of about 60 cfs in the lower Rio Chama (RM 28 to RM 30.3) (Harvey 2022 Section 3.1.4.2. *Water Temperature*).
        - **Water Chemistry.** Changes in the surface water to groundwater composition included increased solute concentrations in the groundwater, higher bicarbonate-to-chloride and lower sulfate-to-chloride ratios that are attributed to water-rock interaction and microbial respiration in the groundwater, including sulfate reduction, which was attributed to less flooding as a result of dam operations (Harvey 2022 Section 3.1.4.3. *Water Chemistry*).
    - Ice formation is very unlikely to have any significant geomorphic effects on Rio Chama (Harvey 2022 Section 3.1.5. *Ice Processes*).
- **Physical habitat changes from system changes** include**:**
    - The pre-dam floodplain is now hydrologically disconnected and hosts upland plant species (Figure 4) (Harvey 2022 Section 3.2.2 *Floodplain Morphology*).
    - Vegetation extends into the river channel (Figure 5) (Harvey 2022 Section 3.2.2. *Floodplain Morphology*).
    - The channel has narrowed with fewer side channels (Figure 6). (Harvey 2022 Section 3.2.3. *Channel Morphology*).
    - Vegetation encroachment from raised baseflows and reduced flood flows counters expected bank erosion below the dam. Erosion of hydrologically disconnected terraces increases sediment loading to the channel—but also facilitates formation of lower-elevation surfaces that are hydrologically connected to the river, thus enabling riparian vegetation colonization and succession (Figure 7). (Harvey 2022 Section 3.2.4. *Hydraulics and Sediment Transport*).
- **Ecological responses to the altered physical habitat** include**:**
    - Vegetation changes have reduced riverine wetlands and increased upland plant species) (Harvey 2022 Section 3.3.1.7. *Vegetation Trends*). Vegetation encroachment, promoted by raised baseflows and reduced flood flows, has stabilized banks (Harvey 2022 Section 3.2.4. *Hydraulics and Sediment Transport*).
    - Macroinvertebrates have been impaired due to the stable temperature regime below the dam and fine sediment deposition (Harvey 2022 Section 3.3.2.1. *Macroinvertebrates*).
    - Fish are now dominated by non-natives such as brown trout (Harvey 2022 Section 3.3.2.2. *Fish*).

- Significant reduction in flow following spawning during the egg incubation-hatch periods between mid-December and early April can result in desiccation of the redds, ice damage to redds, fines sedimentation in the redds, and potentially the loss of a significant portion of a cohort of fish (Figure 8) (Harvey 2022 Section 3.3.2.2. *Fish*).
- The paucity of amphibian data makes it difficult to assess any dam impacts on the amphibian population in Rio Chama (Harvey 2022 Section 3.3.2.3. *Amphibians).*
- Ice and turbidity affect wintering bald eagles' ability to forage for fish, and Fogg et al. concluded that 200 cfs flows limit ice formation to maximize bald eagle feeding opportunities (Harvey 2022 Section 3.1.5. *Ice Processes*)

* **Relationships between ecological and physical habitat changes** include:
    - Rushes and sedges with dense roots trap fine sediment and resist erosion (Figure 9)—a biogeomorphic feedback promotes floodplain growth and contributes to channel narrowing and changes to a single channel (Harvey 2022 Section 3.4. *Fourth Order Impacts*).
    - Shrub-scrub wetland plant communities, including coyote willow, reinforce roots and stabilize riverbanks throughout the Rio Chama as well as induce overbank sedimentation (Figure 9) (Harvey 2022 Section 3.4. *Fourth Order Impacts*).
    - Pre-dam floodplain surfaces and terraces support Rocky Mountain juniper, cottonwood, oak, and box elder trees. River erosion and tree fall introduces large woody debris into the river, especially downstream of the Rio Gallina (Figure 10). Woody debris provides in-channel habitat for macroinvertebrates and fish and nucleates mid-channel bars that form habitat that is inundated frequently and rapidly colonized by coyote willow. Large woody debris also increases plan form complexity (Figure 11) (Harvey 2022 Section 3.4. *Fourth Order Impacts*).

Figure 4. Upland Rocky Mountain juniper and sagebrush on pre-El Vado Dam floodplain (T1) in the middle ground and active floodplain surface in the foreground (RCFP) (Harvey 2022 Section 3.2.2. *Floodplain Morphology*).

Figure 5. Vegetation-stabilized pre-dam gravel bar at RM 1.5. Note Rocky Mountain juniper growth on the bar surface (RCFP) (Harvey 2022 Section 3.2.4. *Hydraulics and Sediment Transport*).

Figure 6. Bar accretion leading to channel narrowing at Archuleta Ranch site, RM 7. Infilled former channel is located along the base of the higher elevation terrace (RCFP) (Harvey 2022 Section 3.2.3. *Channel Morphology*).

Figure 7. Cutbank erosion at RM 25.1 following a flow of 3,800 cfs in May 2019 that removed hydrologically disconnected terraces and upland vegetation on the left side of the channel and caused point bar accretion with coyote willow succession on the right bank (RCFP) (Harvey 2022 Section 3.2.4. *Hydraulics and Sediment Transport*).

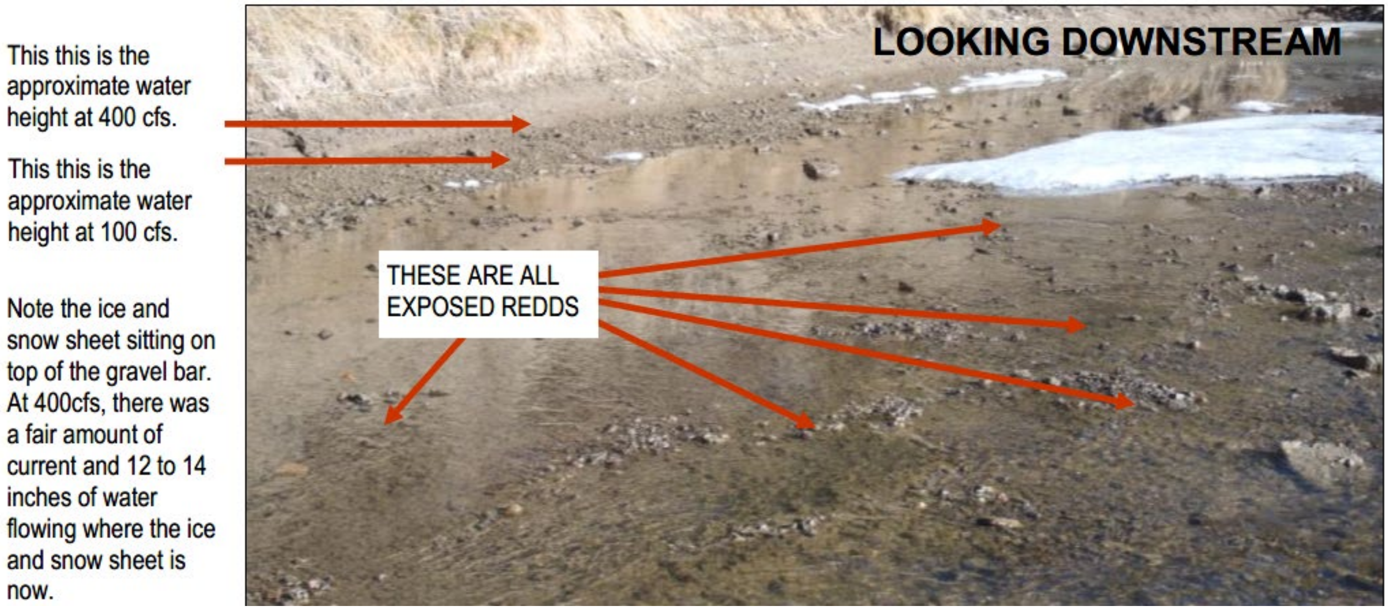

Figure 8. Downstream view of the exposed bed of Rio Chama (RM 9.6) at a flow of 42 cfs on January 1, 2012. Arrows indicate the approximate locations of the water surface at flows of400 cfs, when spawning occurred, and 100 cfs and the locations of exposed redds (annotated photograph courtesy of Noah Parker, Land of Enchantment Guides, 2012) (Harvey 2022 Section 3.2.2.2. *Fish*).

Figure 9. Root reinforcement of the channel bank by Palustrine Emergent Wetland vegetation, including sedges and rushes (RM 15) (RCFP) (Harvey 2022 Section 3.3.1. *Floodplain and Aquatic Vegetation*).

Figure 10. Large woody debris at the head of a mid-channel bar, RM 26 (RCFP) (Harvey 2022 Section 3.4. *Fourth-order Impacts*).

Figure 11. Upstream view of recent sediment deposition and coyote willow colonization of mid-channel bar formed below large woody debris accumulation at RM 26 (RCFP) (Harvey 2022 Section 3.4. *Fourth-order Impacts*).

2.2. Economic Research (Chermak and Stradling 2022)

2.2.1. Study Approach

In the UNM study, *An Economic Evaluation of Peak Flow Management on the Rio Chama*, Chermak and Stradling examine the potential to add economic value to streamflows in the Rio Chama by increasing recreational visitors or by timing hydropower generation to peak demand periods. This study also identifies areas where further research is warranted and proposes a plan for future site-specific data collection. Please see Chermak and Stradling 2022 (Section 1.2. *Study Aims and Methods*) for a description of the study approach and results. See the Economic Report Attachment.

As there are no substantive consumptive uses of the waters of the Rio Chama between the El Vado and Abiquiu Reservoirs, the economic value centers on instream-flow values and economic impacts of the El Vado-Rio Chama system, including:

- short-term expenditures by visitors, which depend on daily conditions;
- non-use values, which are impacted by long-term trends; and
- electricity values, which change every 5 minutes.

Changing water releases from the dams on the Rio Chama would change both the ways in which the water is used and economic impacts from the river. Even changes that do not impact the net economic value of the river may result in the water's benefits being transferred from one group of users to another. For example, changing from the current run-of-river hydropower generation to optimizing releases to increase high-value hydropower output may reduce the value of downstream fishing. Complex trade-offs between competing water uses may be more difficult to see when benefits and costs are incurred by different communities and over different timeframes (Chermak and Stradling 2022 Section 1. *Introduction and Overview*).

This evaluation uses a combination of economic and hydrologic modeling to calculate an economic value for Rio Chama water under baseline model conditions. The authors then model the economic impacts of change scenarios suggested by Reclamation (Chermak and Stradling 2022 Section 3. *Model*). The study develops a cost-benefit framework incorporating dimensions of value associated with the Rio Chama.

2.2.2. Summary of Results

Chermak and Stradling (2022) examine the potential to add economic value to water flows in the Wild and Scenic reach of the Rio Chama by increasing recreational visitors or by timing hydropower generation to peak demand periods. This list highlights some of the findings from Chermak and Stradling 2022.

- **Hydropower.** The study's hydropower model estimated average yearly power values for El Vado Dam between $841,471 and $1,234,901. See Chermak and Stradling 2022 Section 4. *Market Values: Hydroelectric Power* for a description of the model and assumptions. Hydroelectricity is a significant source of non-greenhouse-gas-emissions-producing electricity generation in the United States.

- **Recreation.** Chermak and Stradling found that modeling indicated that the highest value use is recreational as "the river reach and the reservoir provide the majority of value associated with the river above Abiquiu, and the indirect economic impact of tourism is also substantial." (Chermak and Stradling 2022 Section 1.3. *Outcomes).* Most of this value is produced by recreational visits to El Vado Reservoir and the downstream reach of the Rio Chama and is substantially flow-dependent.
  - **Reach Recreation.** Fishing and rafting are the primary value drivers for reach recreation in the Rio Chama downstream of El Vado Dam. Annual economic values were estimated to range from $2 million to $4 million. See Chermak and Stradling 2022 Section 5. *Reach Recreation* for a description of the model and assumptions.
  - **Reservoir Recreation.** This study provides preliminary valuation for the Rio Chama system above Abiquiu Reservoir, which produces an estimated average of $26 million in economic value every year. While study did not evaluate economic impacts from Heron or Abiquiu Reservoirs recreation, the authors found that Heron Reservoir recreation is a substantial part of the value of the overall system. Water elevation does help predict visitor use at reservoirs. At El Vado Reservoir, a 1-foot increase in summer water elevation corresponds with 20 additional weekly visitors, with a confidence interval between 10 and 30. Year and month fixed effects are highly significant. See Chermak and Stradling 2022 Section 6. *Reservoir Recreation* for a description of the model and assumptions.
- **Ecosystem Services.** *Ecosystem services value* describes the non-use benefits provided by the natural system in the Rio Chama canyon, for both experiences (e.g., visits) and consumption (e.g., fish). The Rio Chama's riparian ecosystem provides a home for a significant wildlife population. In general terms, the impact of hydroelectric production on fish populations is mixed as dropping water levels could strand fish or eggs on banks while pulsed flows could provide spawning, hatching, and migration cues for some species. Environmental valuation data was elusive. Based on the limited data available to tie specific environmental outcomes to flow patterns, ecosystem values ranged from $11,000 to $312,000. Chermak and Stradling assert that this is almost certainly a gross underestimation of the true value of environmental services produced by the Rio Chama system. See Chermak and Stradling 2022 Section 7. *Ecosystem Services Valuation* for a description of the model and assumptions.
- **Indirect Impacts on the Local Economy.** Rio Arriba County benefits from indirect economic impacts from tourism. Local spending on gasoline, food, retail goods, lodging, guides, and rentals dwarf the impact of direct reservoir entry or rafting fees. No data specific to the Rio Chama area have been collected, but Chermak and Stradling (2022) provided estimates of average local spending per trip ranging from $270 for a fishing and reservoir trip to $940 for a rafting trip. See Chermak and Stradling 2022 Section 8. *Indirect Impacts on the Local Economy* for a description of the model and assumptions.

2.2.3. Scenario Analysis

Chermak and Stradling 2022 compared the economic impact of alternative flow scenarios to the economic value of baseline flows. Scenarios were chosen to reflect proposed changes or potential areas of interest for Rio Chama stakeholders.

- **Matching Reservoir Evaporation.** Shifting SJCP outflows from Willow Creek to balance evaporation at Heron and Abiquiu Reservoirs has no effect on yearly outcomes. Changing storage location had no effect on the economic outcomes in the through-area.
- **Changing the Dock at Heron Reservoir.** The New Mexico Sailing Club Heron Lake marina dock is unusable when water levels are low. Economic modeling found dock accessibility has no effect on the number of recreational visitors to the lake. Because dock accessibility has no effect on the number of recreational visitors to the lake, Chermak and Stradling found no increased economic value is associated with the lower dock. However, adding recreation value associated with Heron Reservoir visitation more than triples overall economic value under historical flow patterns and quadruples it under high-water flow patterns. Despite decreases in El Vado recreation values and hydroelectric revenue under this scenario, increased visitation to Heron Reservoir more than makes up for losses incurred.
- **Weekend Versus Constant Flow.** Further managing summer weekend streamflows to ensure that they always exceed 600 cfs, the minimum flow needed for downstream rafting, increases the system's overall economic value by 3.3 percent. Increased weekend flows improve all dimensions of value except for reach recreation, which decreases by less than 1 percent. The biggest effect is a 28 percent increase in reach recreation value. Hydroelectric revenue increases by approximately 10 percent.
- **Blue Ribbon Tailwater Fishery.** While conclusions that can be drawn about a potential Blue Ribbon tailwater fishery in the Rio Chama are limited, Chermak and Stradling theorize that increasing the value of the angling in this location and seeking Blue Ribbon Tailwater Fishery status could produce significant positive economic effects for the region as well as increasing the value associated with fishing trips to the Rio Chama.

Retaining water at Heron Reservoir has net negative impacts for the study area, but substantial economic benefits when Heron Reservoir recreational values are incorporated. Existing data do not adequately characterize the economic impacts of a low-water scenario at Heron Reservoir. See Chermak and Stradling 2022 Section 10. *Scenario Analysis* for a description of the model and assumptions.

2.3. Legal Summary (Utton 2022)

In the *Law of the Rio Chama*, the Utton Transboundary Resources Center at UNM explored the constraints of, and flexibilities inherent within, the Law of the River to identify and characterize the most salient constraints and flexibilities, particularly for the Rio Chama between El Vado and Abiquiu Reservoirs. The investigation comprised scoping and mapping exercises to determine relevant law as well as evaluation of both the "hard law" (i.e., laws on the books such as treaties, statutes, and case law) and "soft-law" (i.e., law-in-action such as policy, management, and operations). The Utton Center compiled this work for the Rio Chama, which underlies this legal analysis, available through the Utton Center's website (Utton 2022 Section I. *Introduction)*.

Please note that, for the purposes of this transmittal report, the following summary is an extremely simplified version of the Utton 2022 description of the legal framework and does not include the extensive references noted in Utton 2022. Please read the original as provided in an attachment to this transmittal summary report for a fuller description of these complexities and citations.

2.3.1. Legal Context

Water operations in the Rio Grande Basin work within a complex socio-ecological system where geography, hydrology, law, economics, and policy and management decisions control the flow and allocation of water. Moreover, Rio Chama operations take place within a complex and fragmented multi-jurisdictional space, including western water law; environmental law; and the sovereignty, livelihood, and economic development needs of native American tribes and Pueblos. International, Federal, State, and local authorities control the allocation and use of water in the basin, as well as the associated (or derivative) regulatory and operational mandates (Utton 2022 Section II.A. *Objective and Methodology*).

2.3.1.1 Legal Framework and Boundaries

The three bases of Federal action in the basin are described in Utton 2022 Section III. *Legal Framework: Law of the River*.

- **International treaties and interstate compacts.** Interstate compacts like the Rio Grande Compact are the preferred method of interstate allocation of water. Under the compact clause of the U.S. Constitution, interstate compacts require congressional consent, which when conferred has the effect of transforming an interstate compact into Federal law. Interstate compacts are also codified as State law.
- **Federal water projects.** The Reclamation Act of 1902 charged Reclamation with responsibility for the management and operation of its reservoirs—even after the termination of repayment obligations of individual project beneficiaries, such as irrigators. While projects are authorized by law, Reclamation must comply with State water law. Despite this limitation, states may not impose conditions on Reclamation projects that would frustrate congressional directives.

  Public Law 100-522 authorizes storing native water at Abiquiu within the space allocated for San Juan-Chama Project water storage space if that space is not used.
- **State law and water rights.** New Mexico's Constitution administers water rights under the doctrine of prior appropriation and beneficial use. While the term beneficial use is not defined under the New Mexico Constitution, case law and statutory law have characterized beneficial use as irrigation, domestic, municipal, and industrial, game and fish, and endangered species uses. There is no priority scheme by which to allocate water by type of use during shortages. After 1907, new appropriations of surface water in New Mexico required the user to obtain a permit from the Office of the State Engineer, and the priority date for any resulting right is generally that of the first use. Environmental flow rights do not require a diversion to put water to beneficial use and their emergence in New Mexico has shown a diversion is not required to develop a water right. Water rights adjudications are, characteristically, "very simple in design [but] very complex in execution." Out of necessity, then, the State Engineer, the New Mexico legislature, water

users, and local communities have looked elsewhere to use various shortage sharing strategies to answer the most critical question in water law—what to do when there is not enough water to go around.

- **Environmental law and court cases.** In 1994, the Rio Grande Silvery Minnow was listed as endangered under the Endangered Species Act (ESA), and is also listed as endangered under New Mexico state law. However, because the silvery minnow has been extirpated from the Rio Chama, the Endangered Species Act and its subsequent minnow operation requirements do not apply to the reach of river that this report covers. Still, storage and water operations on the Rio Chama for Rio Grande ESA compliance must be considered, as it is a tributary to the Rio Grande, and water operations on the Rio Chama could affect operations on the Rio Grande. For example, the Rio Chama can provide support flows to achieve these pulses in the Middle Rio Grande reach. Minnow-related legal protections have complicated New Mexico's efforts to comply with the Rio Grande Compact by changing constraints of state water priorities, intersecting with Federal obligations to Native American Pueblos. As a legal hierarchy, the ESA in theory forms the cornerstone of the modern Law of the River for the Rio Grande. Federal law such as the ESA may preempt contrary state law, according to the Supremacy Clause of the U.S. Constitution.
    - The 2001 Conservation Water Agreement was a remarkable new tool negotiated by parties to the silvery minnow litigation as a way to use New Mexico's Rio Grande Compact credits in new and creative ways to benefit the minnow. It required the consent of the Rio Grande Compact Commission to deviate from normal operations, which was granted. It served as the basis for the 2003, 2008, and 2016 Emergency Drought Water Agreements. All of these agreements allow for flexible water management within the constraints of Biological Opinions, New Mexico water law, and the Rio Grande Compact.
    - The 2005 settlement agreement between the City of Albuquerque and *Rio Grande Silvery Minnow v. Keys* plaintiffs authorized an environmental pool within the City's authorized storage space at Abiquiu Reservoirs to protect and restore the ecological integrity of the Rio Grande with assurances that Reclamation would not curtail the City's San Juan-Chama Project water.

      Since 1988, the Rio Chama between El Vado and Abiquiu Reservoirs has been afforded environmental protections for its unique aesthetic and natural values under the Wild and Scenic Rivers Act. land, timber, and mineral-resource development are constrained, and Federal agencies are precluded from developing any "water resources project[s]" that may adversely affect the river's values. However, the Federal government can claim a reserved water right for flows sufficient to meet the purposes of the wild, scenic or recreational designation for a river.

2.3.1.2 Operational Framework

Major high-level constraints tend to dominate water managers on both Rio Chama and Rio Grande. Operational constraints include:

- A complex accounting of "native" Rio Grande Basin flows and "non-native" or "imported" flows is required for New Mexico to achieve both legal—and physical—compliance with the Rio Grande Compact. Under the Supplemental Water Program, Reclamation leases surplus San Juan-Chama water, which it stores in Abiquiu Reservoir in "up to" 20,000 acre-feet of space leased from ABCWUA; the water is subsequently released for the silvery minnow. Reclamation then exchanges this Project water for native Rio Grande water; accordingly, MRGCD only diverts San Juan-Chama water and so an equal amount of native water flows unimpeded, for "beneficial instream flow." This accounting scheme presents no major legal issues since San Juan-Chama water is not required, under the Rio Grande Compact, to be delivered to Texas and this Project water must be consumed within the Middle Rio Grande (Utton 2022 Section V.C.1. *Interagency/Multi-stakeholder Exchanges and Agreements*).
- **Abiquiu Reservoir**—through which native and non-native flows pass—is operated "primarily" for flood control purposes.
- Any perceived or actual shortage to allocations through altered reservoir operations could injure water rights. For irrigators this is a matter of livelihood, and for Pueblos, a matter of livelihood and sovereignty (Utton 2022 Section II.C. *Agency Perspective*).

Operations at Heron, El Vado, Abiquiu, Cochiti and Elephant Butte Reservoirs thus store and release water to meet a variety of demands on different temporal scales, with water that is both "native" to, and imported from, outside the Rio Grande Basin. Reservoirs serve as banks; water managers—both government agencies and quasi-government institutions—serve as brokers; and law and policy are the "rules of the game (Utton 2022 Section IV.A.1. *Operational Framework URGWOM Overview*). Reclamation views reservoir operations flexibility as a tool to meet these various obligations, including ESA requirements, while enhancing ecological resilience, including meeting—or "enhancing"—its water delivery capabilities during drought.

2.3.1.3 Modeling Tools

URGWOM is a decision-support and systems modeling tool to help plan, manage, and account for water in the Rio Chama and the Rio Grande. In its modeling of water storage and delivery operations, URGWOM models focus respectively on accounting, water operations, forecasting, and planning. Policy rules, therefore, are a fairly high-resolution attempt at modeling, both in substance and in terms of hierarchy, the legal authorities controlling the allocation and use of water in the basin, as well as the associated (or derivative) regulatory and operational mandates.

The approximately 180 policy rules are a fairly high-resolution attempt at modeling—both in substance and hierarchy. Appendix 1 to Utton 2022 presents an annotated summary of this URGWOM's ruleset. The legal infrastructure dictates many operational rules and assumptions in these models. While many legal mandates, such as provisions of the Rio Grande Compact or reservoirs' authorizing legislation, translate neatly into operational requirements and water accounting schemes, assumptions may be built into the model's representation of other legal authorities (Utton 2022 Section IV.A.1. *Operational Framework URGWOM Overview*).

2.3.2. Potential System-Wide Flexibilities

Reservoir operations may be ripe for more flexible, optimized configurations (Utton 2022 Section 1. *Introduction*). In the face of water-short conditions, such configurations should offer both resiliency and adaptive capacity.

There is inherent flexibility within the water management system. This type of flexibility, however, is non-linear, involves multiple "colors" (different types of water rights and various sources) of water, tends to be transactional, and often occurs "off balance sheet. Regularly, it occurs as a function of ground-level water managers diligent and daily operations coordination, which involves multiple water users and government agencies. This sort of flexibility has not lent itself to description and exploration—and the results of individual laws and conflicts which dominate water law; nonetheless, it embodies the most important and dynamic boundary conditions which govern the Rio Chama as a system (Utton 2022 Section II.C. *Agency Perspective*).

Making water management more flexible is a complex endeavor that requires mastery of many different disciplines but ultimately depends on the open-mindedness of today's water managers (Utton 2022 Section VII.D. *The Flexibility of Law and Policy*).

Rules are made by people and can be changed by people. 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. Rule changes are not made overnight but rather through long-term contemplation, socialization, and optimization of physical and political circumstances (Utton 2022 Section VII. *Finding Institutional Flexibility*).

3. Recommendations

This section summarizes recommendations made in the University of New Mexico reports for Reclamation, partners, and stakeholders to consider.

3.1. Research

The understanding of the system gained through these study efforts and the identification of operational, legal, and institutional constraints could be enhanced through additional studies and modeling to further evaluate operational flexibilities and the impacts of changes in flows.

3.1.1. Ecosystem Research

Researching the biogeomorphic responses to the planned flow releases that have occurred since 2011 will help develop a better understanding of the dynamics of the novel ecosystem that has evolved in the Rio Chama over the last 85 years. These insights will provide a more robust basis for identifying a suite of flows for both maintaining and improving the novel ecosystem through adaptive management processes (Harvey 2022 Section 5.1. *Research and Monitoring Needs).*

3.1.1.1 Research Sites

Four RCFP research sites in the canyon section of the Rio Chama were established in 2011, and two more sites downstream of the Rio Gallina were established in 2013. Since the initial topographic and bathymetric surveys of the sites were completed, morphologic, sedimentological, and botanical changes have been observed at all the sites in response to the planned flow releases. Research is needed to analyze the changes that have occurred at each of these six sites:

- Resurvey the topography and bathymetry of the sites
- Resurvey botanical resources
- Resample bed material

These resurvey results could be used with the flow release experiments to analyze the Ecosystem responses since the initial surveys. Hydrodynamic modeling could then be conducted at each of the sites based on the new topography and bathymetry. Comparing the botanical and bed material sampling would help document changes and further our understanding of the relationships between morphologic, sedimentological, and botanical factors within this unique ecosystem (Harvey 2022 Section 5.1. *RCFP Research Sites*).

3.1.1.2 Modeling

Morrison and Stone (2015a and 2015b) developed a Systems Dynamics model of the Rio Chama to provide a more holistic approach for comparing flow alternatives on the basis of their impact ton environmental and recreational processes, as well as other important basin considerations. Managers and stakeholders can use comparative metrics, such as the success ratios presented in their research, to justify or dispel perceived institutional or physical capacity issues and can move forward with new operational strategies within an adaptive management framework

(Benson et al. 2013). The same model has been used to evaluate the economic values of alternative flow scenarios (Harvey 2022, Section 4. *The Rio Chama as a Novel Ecosystem*).

3.1.1.3 Sediment

El Vado Dam effectively has a 100 percent trap efficiency for the morphologically significant sand and coarser sediment while it passes a significant quantity of fine sediment. To understand the morpho-dynamics of the Rio Chama and attendant formation and maintenance of both in-channel and channel margin habitats, a sediment mass balance (inputs – outputs = change in storage) is needed. In addition, estimating sediment delivery to Abiquiu Reservoir is important to understand its potential impacts on storage of native Rio Chama water in Abiquiu Reservoir (Harvey 2022 Section 5.2. *Sediment Mass Balance*). Repeat bathymetric surveys of El Vado (Reclamation) and Abiquiu (USACE) Reservoirs would provide validation data.

Estimates of the periodic influx of sediment from debris flows can be assessed by field measurement of deposits and sampling for gradations. Dating of debris flow deposits in the larger tributary drainages will provide an estimate of their recurrence interval. Comparisons of these and future debris flows would help inform the amount of materials coming into and entrained in the river.

3.1.1.4 Water Temperatures

Installing air and water temperature data loggers between El Vado Dam and the Big Eddy boat take-out would provide a year-round temperature profile for the river. The role of hyporheic exchange, as measured by a network of piezometers, in modulating water temperatures could be coupled with assessment of fines-effects on spawning habitat and on water chemistry (Harvey 2022, Section 5.3. *Spatial Relationships*).

3.1.1.5 Pulsed Flow Responses

The degree of damage or benefit related to pulsed flows depends on local fish populations and conditions. More research on particular aspects of pulsed flow impacts on fish life cycle is required (Chermak and Stradling 2022 Section 10.4.2. *Dam Impacts on Fish Populations*).

3.1.1.6 Habitat, Amphibians, and Macroinvertebrates

The spatial distribution, extent, and suitability of brown trout spawning habitat has yet to be determined in the Wild and Scenic reach. Riffles provide the bulk of the macroinvertebrate habitat. While riffles have been mapped, strategic sampling of both riffles and macroinvertebrates would provide valuable information on the role of the tributaries and provide a basis for determining suitable flows for optimizing productivity (Harvey 2022 Section 5.3. *Spatial Relationships*).

Amphibian monitoring will determine whether habitat created from vegetation and physical processes is used. Monitoring fish use and macroinvertebrates at large woody debris sites will help to quantify the added ecological value of the more dynamic channel that has resulted from the planned flow releases (Harvey 2022 Section 5.4. *Vegetation Effects on Channel Processes*).

Standardized light trapping of adult aquatic insects by river guides, private boaters, and other groups who frequently float the Rio Chama using the very successful approach developed by Kennedy et al. (2016) in the Grand Canyon could significantly increase our understanding of the effects of flow fluctuations on aquatic insect abundance. Reclamation's WaterSMART program has funded an initial investigation in 2020 through at least 2022. This program not only could provide data, but also functions as an outreach for citizen science. Recreators who participate in this citizen science are educated about the weekend flows and about the importance of data about indicator species for developing flow management options (Harvey 2022 Section 5.5. *Effects of Flow Variations on Insect Population Dynamics*).

3.1.1.7 Vegetation

Measurements of the shear strength of root-reinforced soils can be used to evaluate the erodibility of the root-reinforced alluvium and the potential for flow-induced adjustment of the river. Mobile-boundary, two-dimensional hydrodynamic modelling (SRH-2D), coupled with field measurement, could be used to evaluate channel margin deposition and its related features and identify the range of flows required to maintain them. Identifying the range of flows required to mobilize large woody debris and evaluating the role of large woody debris in nucleating mid-channel bars and thus increasing channel complexity could also address the added ecological value of a more dynamic river system (Harvey 2022 Section 5.4. *Vegetation Effects on Channel Processes*).

3.1.1.8 Structures

The RCFP needs to continue monitoring the river near structures and the two U.S. Forest Service roads, FS 151 and FS 474, that parallel portions of the Rio Chama downstream of the Rio Gallina. At FS 474 at RM 25.2, the river eroded about 31 feet of the floodplain in a 1-year period between 2017 and 2018 as a result of change in planform geometry, requiring a portion of the road to be relocated (Harvey 2022 Section 5.6. *Flow Variations Effects on River Infrastructure and River Banks*).

3.1.2. Economic Research

Chermak and Stradling (2022) noted that further research could help refine economic analyses for potential actions within the Rio Chama.

3.1.2.1 Reservoir Recreation Values

Better data from visitors at Heron and El Vado Reservoirs could improve our understanding of visitor and spending patterns and their relationship with reservoir height. Further analysis should include extending economic valuation to fully incorporate recreation at Heron and Abiquiu Reservoirs, given the inevitable effects of flow management changes on those reservoirs and the disproportionate economic effects on reservoir recreation (Chermak and Stradling 2022 Section 6. *Reservoir Recreation*).

3.1.2.2 Environmental and Cultural Values

Further research in this area should include ecosystem modeling over a multi-year period, which may capture important flow-driven, long-term changes in the system's overall economic value. The presence of previous Pueblo settlements located along the Rio Chama between El Vado and Abiquiu Reservoirs also speaks to cultural value that is difficult to quantify. The ways in which streamflow changes may affect these cultural dimensions of value are not known (Chermak and Stradling 2022 Section 7 *Ecosystem Services Valuation*).

3.1.2.3 Fishery Values

More direct research focused on the effect of streamflow changes on fish population dynamics would help provide a foundation to evaluate the economic potential for establishing a Blue Ribbon tailwater fishery in the Rio Chama below El Vado Dam. Fish habitat issues could be alleviated by allowing reservoir releases currently scheduled in December to be spread out over December, January, and February. This area would benefit from directed research into the specific fish biology relevant to the Rio Chama (Chermak and Stradling 2022 Section 10.4. *Blue Ribbon Tailwater Fishery*).

3.1.2.4 Hydropower Values

There is no current research examining the value of using a small hydropower dam like El Vado to support the integration of renewable energy, and the existing studies are too different in scope to provide meaningful comparisons or valuation. A comprehensive evaluation of the monetary benefits of optimizing hydropower could provide reference values against which to compare other benefits. This would need to include considering the costs and benefits of changing flows hourly for load following rather than weekly and seasonally for downstream water users, environmental flows, and recreation (Chermak and Stradling 2022 Section 9. *Indirect Environmental Impact of Hydroelectricity*).

3.1.2.5 Non-Market Values

The values provided by this modeling process would unquestionably increase in accuracy if current non-market valuation studies could be performed in the Rio Chama area, and we recommend that further primary research be undertaken. (Chermak and Stradling 2022 Section 9. *Indirect Environmental Impact of Hydroelectricity*).

3.2. Operations and Infrastructure

SJCP flows between El Vado and Heron Reservoirs could be scheduled to meet a range of objectives, depending on the water availability. These are listed in Table 2 as potential options for flow schedules as a basis for discussion for what Rio Chama flows might look like to optimize river and habitat health (Figure 12).

The flow recommendations in Harvey 2022 were based on the Instream Flow Incremental Method (IFIM) procedure that aims to optimize the available habitat for the various life stages. Current management guidelines are based on the Management Plan (Fogg et al. 1992). Harvey 2022 recommends modifications to enhance the ecosystem. Environmental flow recommendations to improve the novel ecosystem were initially developed collaboratively by the RCFP (Figure 12) and then adapted as more information became available.

These potential schedules would allow adding significant regional economic value to the flows with short-term hydropower peak generation and water-based recreation (fishing and boating) and synchronize instream flows to benefit the closely linked environment without adversely affecting downstream water users.

Table 2. Idealized Rio Chama Non-Consumptive Flow Regime to Meet Ecosystem Objectives*

Flows						Ecological Objectives	
Purpose	Peak Magnitude (cfs)	Flow Volume (acre-feet)	Recurrence Interval (years)	Duration (days)	Season	Canyon (Wild Reach)	Lower Reach (Scenic Reach)
Maximum controlled release from El Vado	6,000	63,000	10	2 days at peak flow; 21-day total event duration	Spring (Apr-Jun)	Redistribution of tributary debris-flow sediments	Floodplain and low terrace inundation
						Mobilization of bed and bank material	Accelerate lateral migration and point-bar formation in alluvial reaches
						New bar formation and fossilized bar dissection	Creation of off-channel habitat for amphibian and avian species
						Inundation of limited floodplain segments	Recruitment of large woody debris
Spring pulse	4,000	30,000	5	2 days at peak flow; 21-day total event duration	Spring (Apr-Jun)	Redistribution of tributary debris-flow sediments	Floodplain inundation
						Mobilization of bed and bank material	Accelerate lateral migration and point-bar formation in alluvial reaches
						New bar formation and fossilized bar dissection	Riparian plant recruitment
						Creation of fish spawning habitat	Maintenance of off-channel habitat for amphibian and avian species
						Inundation of limited floodplain segments	Recruitment of large woody debris
Bankfull discharge	2,500	18,000	2	2 days at peak flow; 21-day total event duration	Spring (Apr-Jun)	Bed material mobilization and gravel flushing	Bed material mobilization and gravel flushing
						Maintenance of in-channel habitats for fish and macroinvertebrates	Riparian vegetation maintenance
Weekend boating flows	700-1,000	4,000-5,900	NA	3/event	Summer (May-Oct)	Monsoon-season riffle flushing for macroinvertebrates	Monsoon-season riffle flushing for macroinvertebrates
Brown trout spawning	150	17,000-25,000	NA	60-90	Fall (Oct-Dec)	Spawning redd inundation	In-channel habitat maintenance
Winter sustaining flows	100	18,000-	NA	90	Winter (Jan-Mar)	Redd maintenance	In-channel habitat maintenance
						Maintain macroinvertebrate habitat	Maintain macroinvertebrate habitat
						Pool habitat for fish over-wintering	Pool habitat for fish over-wintering

*Annual total discharge about 400,000 acre-feet

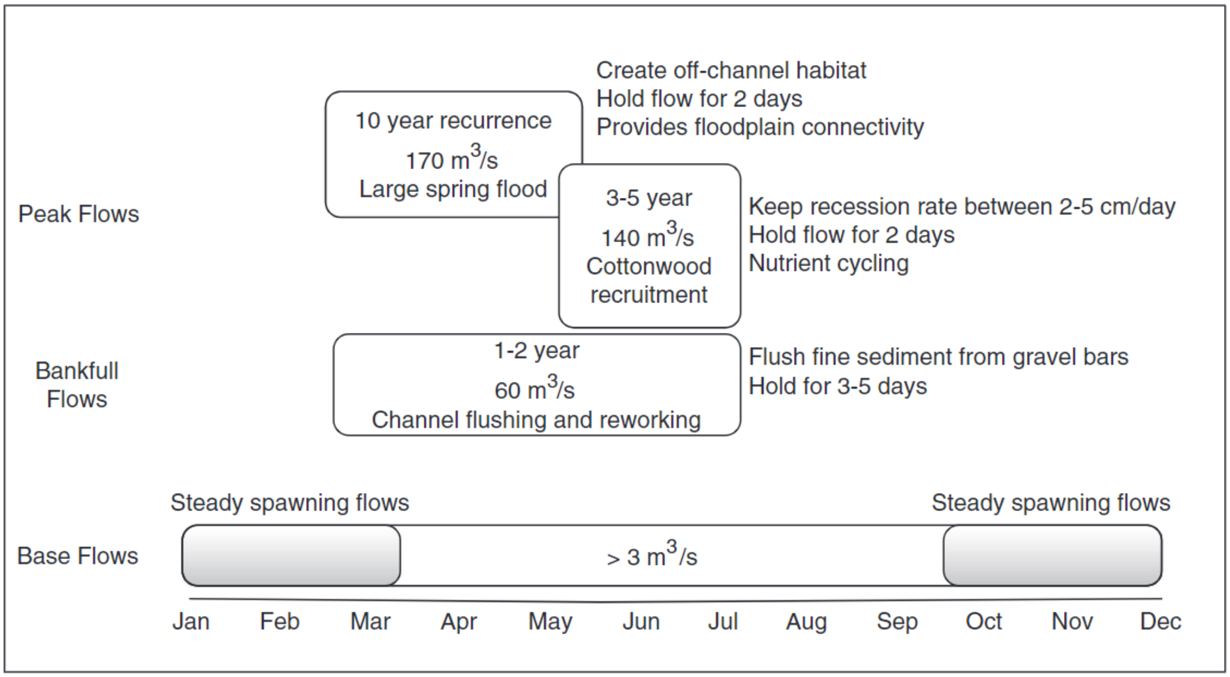

Figure 12. Environmental flow recommendations for the Rio Chama based on a collaborative workshop of hydrology, ecology and geomorphology experts (Morrison and Stone 2015a. Figure 2).

3.2.1. Peak Flows

Water managers and water users, in conjunction with the RCFP team, have and should continue to provide annual peak flows when possible and use the limited time window available for mobilizing debris flow deposits (Harvey 2022 Section 3.1.2.5 *Planned Flow Releases)*. Within the canyon reach of the Rio Chama between El Vado Dam and Rio Gallina, where there is limited potential for channel migration, higher flows could redistribute tributary-supplied sediment, transport sediment, form in-channel habitat, and improve existing habitat for fish spawning and macroinvertebrates. Downstream of the Rio Gallina, the objectives are focused on developing a more dynamic and complex river system that improves both in-channel and floodplain habitats for the benefit of fish, macroinvertebrates, and riparian vegetation (Harvey 2022 Section 4. *The Rio Chama as a Novel Ecosystem.)*

- Flows over about 2,200 cfs inundate the post-dam floodplain.
- Flows over about 3,000 cfs can mobilize the bed material, flush the accumulated fines, and promote lateral migration within alluvial reaches.
- Flows over about 4,000 cfs inundate the pre-dam floodplain.
- Timing for peak and overbank flows to create suitable hydrodynamic conditions for cottonwood establishment when seeds are dispersed in the spring Flow recession rate must not exceed the growth rate of the seedling roots or they become desiccated and die.

- Flows that are greater than bankfull allow sand deposition to create off-channel wetlands, which can provide habitat for amphibians (Harvey 2022 Section 3.4. *Fourth-order Impacts*).

3.2.2. Minimum Flows

Because the Rio Chama Management Plan focuses on supporting a naturally reproducing brown trout population, the following minimum flow recommendations from IFIM studies were developed to support all life stages of the brown trout (Fogg et al., 1992):

- **Year round:** 150 to 700 cfs year round, with 400 cfs as an optimum for spawning and incubation and a minimum flow of 185 cfs to maintain habitat for macroinvertebrates as forage for fish;

- **Spring:** 150 to 300 cfs, with an optimum of 200 cfs for fry; and

- **Summer:** 75 to 300 cfs, with 200 cfs as an optimum for juveniles and adults

(Harvey 2022 Section 3.3.2.2. *Fish*).

3.2.3. Late Season Flushing Flows

Late-season (September through November) surficial flushing flows to mobilize deposited fines (smaller than 0.062 mm) may well benefit the macroinvertebrate community and, therefore, the fish population (Harvey 2022 Section 3.3.2.2. *Fish*).[1]

3.2.4. Winter Flows

A minimum flow of 200 cfs would be needed to prevent ice formation and its adverse impacts on redds and provide open-water winter foraging habitat for bald eagles, appears to be required in the winter (Harvey 2022 Section 3.3.2.4. *Birds*).

Avoid significant flow reductions during the egg incubation-hatch periods that can result in brown trout redd desiccation, ice damage, fine sedimentation—and potentially fish loss—between mid-December and early April (Harvey 2022 Section 3.3.2.2 *Fish*).

Flows are often high through December 31, and then are cut dramatically. Harvey 2022 explores some potential concepts for operational changes to address this that could include:

- Changing operational authorities for the SJCP and Heron Reservoir to allow SJCP water in the Federal pool in Heron Reservoir from being carried over to the next calendar year, which requires Project water to be routed downstream by December 31. The ability to store native water in Abiquiu Reservoir would improve winter flow management (Utton 2022 Section II.B.3. *Rio Chama: Institutional Framework* and VII.C.3. Current Flex *Points for the Rio Chama Reservoirs: Abiquiu Reservoir* and Harvey 2022 Section 3.3.2.2 *Fish*). For the first twenty years of San Juan-Chama Project operations, it was

[1] On November 29, 2022, in coordination with partners, Reclamation released Prior and Paramount water from El Vado Dam for Rio Grande Compact deliveries. This release amounted to a pulse flow of almost 3,000 cfs. Data and monitoring from this event are currently being processed (May 2022).

believed that San Juan-Chama contractors must evacuate their annual allotment of water from the Reservoir by December 31st of every year. This was based on an interpretation of a provision in the Colorado River Project Storage Act. In 1983 the San Juan-Chama Project Engineer proposed that carryover of water be allowed until March 31st of the following year. This was suggested to alleviate the negative effects of reduced flows in January on the trout population in the Rio Chama (Utton 2022 Section VII.C.3. Current Flex *Points for the Rio Chama Reservoirs: Heron Reservoir*).

- Changing how water for the Prior and Paramount lands of the Six Middle Rio Grande Pueblos is stored under Article VII restrictions of the Rio Grande Compact and typically released between the end of the Pueblos' irrigation season, November 15, and the end of the calendar year (Harvey 2022 Section 3.3.2.2 *Fish*).
- Temporary waivers to permit carryover storage to be delayed from December until March or April of the following year initially, and then until September 30 of the following year, when such waivers are "to the benefit of the government," have allowed more favorable winter flow releases since 1984. RCFP has worked with Reclamation in recent years to coordinate winter flows to protect brown trout spawning and recruitment of juveniles into the population, using waivered water from the City of Santa Fe, Albuquerque Bernalillo County Water Utility Authority (ABCWUA), and Reclamation's Supplemental Water Program (Harvey 2022 Section 3.1.1.2. *Flow Duration*).

3.2.5. Rafting Flows

Maintaining minimum rafting flows at 600 cfs throughout summer weekends can increase reach recreation values by 28 percent, or around $1 million, as well as increasing hydropower values. Despite a modest decrease in reservoir recreation values, the change results in an overall increase of about $900,000 (Chermak and Stradling 2022 Section 11. *Conclusions*).

There is a need to continue and enhance the coordination for rafting flows. Reclamation has worked with several of the San Juan-Chama Project contractors, including the Albuquerque-Bernalillo County Water Utility Authority and the Santa Fe Water Utility, and has used water that it has leased for endangered species protection on the Rio Grande (Reclamation's Supplemental Water Program) to modify flow patterns and increase flows in the Rio Chama during summer weekends in which MRGCD's irrigation releases are insufficient to support rafting (Chermak and Stradling 2022 Section 1.1. *Study Area Description*).

3.2.6. Hydropower

Intraday flexibility in dam releases could increase the value of hydropower generated by between 3 and 10 percent. (Chermak and Stradling 2022 Section 11. *Conclusions*).

3.2.7. Sediment Management and Turbidity

Potential structural options to address sediment and turbidity concerns include:

- Building a **gated intake tower.** A more comprehensive way of addressing the turbidity problem would be the addition of a gated intake tower to the lower-elevation power-station outlet at El Vado Dam. A gated intake tower would have the added benefits of allowing sediment to pass through the dam, thereby preserving reservoir capacity. An additional benefit of the reduced sediment pass-through would be reduced abrasion on the recently refurbished power station turbines (Harvey 2022 Section 3.1.3. *Sediment Supply* and Section 4. *The Rio Chama as a Novel Ecosystem*).
- **Developing and using a maintenance dredging program in the reservoir bed:** A maintenance dredging program could be used to remove the accumulated sediment to an elevation below the low-level outlet. However, even though the El Vado sediments have very low concentrations of metals and very few human-made organic compounds, disposal and dewatering of the dredged material may be problematic (Harvey 2022 Section 4. *The Rio Chama as a Novel Ecosystem*).
- **Raising the outlet works to the lower-level power station:** Alternatively, the outlet works to the lower-level power station outlet could be raised in a similar manner to the outlet work modifications that were completed by Reclamation for the non-hydropower outlet works at El Vado Dam between 1965 and 1966. While this approach would provide an immediate solution to the turbidity problem, the effectiveness would be time-limited, as sediment would eventually accumulate to the new outlet elevation, with an attendant loss of reservoir storage capacity unless it was accompanied by a maintenance dredging program (Harvey 2022 Section 4. *The Rio Chama as a Novel Ecosystem*).

3.2.8. Temperatures

Water temperatures could be managed for the benefit of the downstream macroinvertebrate community (Peters, 1978) while still maintaining a cold-water fishery (Harvey 2022 Section 4. *The Rio Chama as a Novel Ecosystem*). This temperature regulation could be achieved by changing the outlet works structures at El Vado Dam.

3.3. Legal and Policy

3.3.1. Unresolved Issues

A number of unresolved issues along the Rio Chama, in the Middle Rio Grande, and beyond seem ripe for creative thinking.

- The ongoing Supreme Court litigation regarding groundwater use within the Rio Grande Project attempts to create a new flexible management regime for water deliveries from Elephant Butte Reservoir to Texas stretched beyond New Mexico’s threshold for flexibly interpreting the Rio Grande Compact.
- The resolution of Pueblo water right claims is another opportunity for creative water management thinking. The resolution of Pueblo water right claims in northern and central New Mexico has included commitments to create regional water supply systems and

implement conjunctive management of ground and surface waters. Future Pueblo water rights claims in the Middle Rio Grande may include claims for ecological water, like spring pulse flows and maintained base flows.

- The ongoing corrective action study of El Vado Dam presents an opportunity to think creatively about not only how the dam's current operations can be protected but also how it can be improved to better serve its users (Utton 2022 Section VII.B. *Future Flex Points*).

3.3.2. Potential Reservoir Flexibilities

3.3.2.1 Heron Reservoir

Heron Reservoir is used to store San Juan-Chama Project water only. In 1983, a field solicitor confirming that reading the law to allow for carryover storage and expressed the opinion that carryover waivers could be granted on a case-by-case basis when there are benefits to the United States through more effective Project operations (Utton 2022 Section VII. A.C. 2. *Current Flex Points for Rio Chama Reservoirs: El Vado Reservoir*).

3.3.2.2 El Vado Reservoir

El Vado Reservoir was not built by the Federal government and does not have explicit Federal restrictions on how it may be used, other than those set forth in the Rio Grande Compact. El Vado is often used as a re-regulating reservoir to simplify water operations between Heron and Abiquiu Reservoirs. It is used to store both native and San Juan-Chama water, supplemental water for endangered species, and senior Pueblo irrigation water rights (Utton 2022 Section VII. A.C. 2. *Current Flex Points for Rio Chama Reservoirs: El Vado Reservoir*). Under the 2008 Emergency Drought Water Agreement (EDWA), New Mexico was able to store native water at El Vado Reservoir when it would have otherwise been precluded by Compact Article VII (Utton 2022 Section IV.A.3.a.1. *Emergency Drought Water Agreement*). Utton 2022 notes "El Vado already provides examples of flexible water management. After the designation of the Wild and Scenic reaches of the Rio Chama in 1988, a team was assembled to develop the Rio Chama Instream Flow Assessment. Strategies were developed to release water from El Vado in a manner that would not only serve downstream irrigators but would also enhance the trout fishery and recreational boating opportunities" (Utton 2022 Section VII. A.C. 2. Current Flex Points for Rio Chama Reservoirs: El Vado Reservoir). On Pueblo water rights, Utton 2022 asserts:

> *"It may be the storage of Pueblo water rights that presents the greatest potential for implementing future management flexibility at El Vado. Currently only the Pueblos' Prior and Paramount water rights are stored in El Vado. The amounts and procedures for storage and release of Pueblo water are dictated by a 1981 agreement between the Secretary of the Interior and the Middle Rio Grande Conservancy District. This agreement could be renegotiated in the future. Moreover, when the Pueblos decide to assert their water right claims, storage at El Vado could be a major component of water right settlement discussions. For example, it may be found prudent for the Pueblos' Prior and Paramount irrigation water rights to be carried over from year-to-year in El Vado (Utton 2022 Section VII. A.C. 2.* Current Flex Points for Rio Chama Reservoirs: El Vado Reservoir*)."*

3.3.2.3 Abiquiu Reservoir

In order to increase operational flexibility, USACE could deviate from normal operations at Abiquiu with permission from the Rio Grande Compact Commission. Currently, USACE analyzes planned deviations based on the case-by-case merits of the situation. Impacts to flood potential, reservoir conditions, and expected benefits and consequences should all be considered (Utton 2022 Section VII. A.C.3. *Current Flex Points for Rio Chama Reservoirs: Abiquiu Reservoir*).

Utton characterizes flood and storage operation considerations as "In 1981 Congress authorized the Secretary of the Interior to store up to 200,000 acre-feet of San Juan-Chama water in Abiquiu so long as such storage did not interfere with the primary flood and sediment control functions of the Reservoir. In 1988 Congress also authorized the Secretary of the Army to store 200,000 acre-feet of native Rio Grande water in Abiquiu, so long as San Juan-Chama contractors do not need the space.

The flood control space within Abiquiu is 502,000 acre-feet. Given that 200,000 acre-feet has been allocated to San Juan-Chama or native water storage, if flood control demands are predicted to be in excess of 302,000 acre-feet, USACE will begin to evacuate water from the 200,000 acre-foot conservation pool. USACE can deviate from normal operations at Abiquiu with permission from the Rio Grande Compact Commission. USACE analyzes planned deviations based on the case-by-case merits of the situation." (Utton 2022 Section VII. A.C.3. *Current Flex Points for Rio Chama Reservoirs: Abiquiu Reservoir*).

3.3.2.4 Cochiti Reservoir

Cochiti Reservoir is primarily operated for flood and sediment control purposes. However, deviations from these normal operations currently allow detaining spawning and recruitment flows for the ESA-protected silvery minnow. When runoff conditions would not otherwise permit such flows, water is temporarily stored and released to provide a spring pulse flow that mimics the natural pulse of snowmelt runoff. The Flood Control Act of 1960 requires that such deviations from the Act's Reservoir Regulation Plan be authorized by the Rio Grande Compact Commission (Utton 2022 Section IV.A.3.a.2. *Cochiti Deviations*). In 2018, Congress authorized USACE to create peak flows on the Rio Grande through temporary deviations of operations and both Cochiti and Jemez Reservoirs for a period of five years, once the deviations are resumed. USACE is required to consult with Cochiti and Santa Ana Pueblos on these deviations (Utton 2022 Section VII. A.C. *Current Flex Points for Rio Chama Reservoirs: Abiquiu Reservoir*).

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