An Economic Evaluation of Peak Flow Management on the Rio Chama

San Juan Chama Project, New Mexico
Lower Colorado Basin Region

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Abbreviations and Acronyms

ABCWUA	Albuquerque-Bernalillo County Water Utility Authority
BLM	Bureau of Land Management
CE	choice experiment
cfs	cubic feet per second
CHANS	coupled human and natural systems
CVM	contingent valuation method
FERC	Federal Energy Regulatory Commission
IMPLAN	Impact Analysis for Planning
LACDPU	Los Alamos County Department of Public Utilities
MW	megawatt
MWh	megawatt hour
NOAA	National Oceanic and Atmospheric Administration
PNM	Public Service Company of New Mexico
Reclamation	Bureau of Reclamation
TCM	travel cost method
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
Utton	Utton Transboundary Resource Center

Summary

There are no substantive consumptive uses of the waters of the Rio Chama between the El Vado and Abiquiu Reservoirs. The economic value of this stretch of river is, instead, centered on instream-flow uses and values. Managing these flows in a way that supports non-consumptive uses and values (e.g., hydropower, recreation, fishing, and boating) has the potential to increase the economic value of the river, and, in many cases, can be done in a way that does not negatively affect downstream water uses. In addition, the economies of the rural communities near and along the Rio Chama and its reservoirs, which are generally economically depressed, could greatly benefit from increased economic activity through improved outdoor recreation. However, the potential spatial and temporal trade-offs between alternatives within the region is complex, as is the analysis needed to rule out any impacts downstream.

We model the economic value of alternative management plans to assess the efficacy of, and trade-offs between, alternatives to enhance the economic value of the reach. A catalog of the potential economic factors is developed that includes not only the activity, but also the spatial and temporal aspects of each factor. Benefit transfers are used from the extant literature in order to develop economic valuation models of alternative flow patterns. These models are incorporated into a system dynamics framework that also models the hydrology of the river. The system dynamics model is used to evaluate the impact of alternative scenarios and describe the economic trade-offs involved in each. All dollar amounts are in 2017 constant dollars.

This study provides preliminary valuation for the Rio Chama system above Abiquiu Reservoir, which produces an average of $26 million in economic value every year, excluding Heron and Abiquiu Reservoirs. The majority 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.

There are several means of increasing the economic value of Rio Chama flows. Intraday flexibility in dam releases could increase the value of hydropower generated by between 3 and 10 percent. Maintaining minimum rafting flows at 600 cubic feet per second (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 modeled change results in an overall increase of about $900,000.

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1. Introduction and Overview

This report analyzes the economic impact of non-consumptive water use in the Rio Chama above the Abiquiu Reservoir, then examines the potential consequences of changing water releases from El Vado Dam by modeling the economic trade-offs inherent in the river system. A hydrological model of the Rio Chama from El Vado Reservoir to Abiquiu Reservoir is used as a dynamic system framework (Morrison and Stone 2015a, shown in Figure 1). Economic values are incorporated in order to calculate the total impact of flow changes as well as examine the individual trade-offs that result. This economic valuation suggests ways to enhance the value of the river and shows how changes in water policy can transfer the river's economic benefits between different groups or communities.

Figure 1. Schematic of Rio Chama and diversion points.

The Rio Chama flows from southern Colorado through Rio Arriba County in northern New Mexico, where it joins the Rio Grande. The river and its three large reservoirs provide significant benefits to the surrounding communities. Little consumptive use of river flows takes place above the Abiquiu Reservoir, but the area receives economic benefits from non-consumptive river uses, such as hydropower generation and recreation.

Changing the timing of water releases from the dams on the Rio Chama can alter both the ways in which the water is used locally (mostly non-consumptively) and the economic impact of 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, increasing high-value hydropower output may reduce the value of downstream fishing—moving the water's economic benefits from recreational fishing tourism to hydropower and benefitting power users over local merchants and recreationists. This is a simple example, but 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. In addition, changes in the river's hydrology that improve ecological function in the reach, including in riverine and riparian systems, have potential intrinsic value that is more difficult to quantify.

1.1. Study Area Description

This study examines Heron Reservoir, El Vado Reservoir, and the Wild-and-Scenic-designated reach of the Rio Chama between the El Vado and Abiquiu Reservoirs. Both El Vado and Heron are designated state parks and popular recreational sites for boating and camping. Since Heron Reservoir is a no-wake area, it supports a sailing club and marina. The river reach downstream from El Vado is a popular wilderness rafting destination. The reach and the two reservoirs also support fishing, birdwatching, and hiking. The Rio Chama's riparian ecosystem provides a home for a significant wildlife population.

The Bureau of Reclamation (Reclamation) manages the reservoir operations at Heron Dam in consultation with the 16 contractors to Reclamation's San Juan-Chama Project, and manages operations at El Vado Dam in consultation with the Middle Rio Grande Conservancy District, the irrigation district that owns the storage rights in El Vado Reservoir. Water from Reclamation's San Juan-Chama Project is stored at Heron Reservoir, increasing the natural yearly flow by an average 96,200 acre-feet of water (i.e., the Firm Yield of the San Juan-Chama Project). Each San Juan-Chama Project contractor must release its allocations from Heron Reservoir by the end of the calendar year, unless it has received a waiver from Reclamation allowing it to extend storage into the following calendar year (typically until September 30).

Because recreational rafting in the Wild and Scenic reach of the Rio Chama is a source of significant tourist revenue in the area, Reclamation has worked with several of the San Juan-Chama Project contractors, including the Albuquerque-Bernalillo County Water Utility Authority (ABCWUA) and the Santa Fe Water Utility, and has used water that it has leased for endangered species protection on the Rio Grande (within Reclamation's Supplemental Water Program) to modify flow patterns and increase flows in the Rio Chama during summer weekends in which the Middle Rio Grande Conservancy District's irrigation releases are insufficient to support rafting (Benson et al. 2013 and the Utton Transboundary Resource Center [Utton] 2015).

El Vado and Abiquiu Dams have hydroelectric turbines owned and operated by the Los Alamos County Department of Public Utilities (LACDPU). Although water flows through the dam can be timed, LACDPU does not have the authority to schedule releases, so the units function as run-of-river rather than dispatchable generation (Utton Center 2015). El Vado's generator has a nameplate capacity of 8.8 megawatts (MW), which is achievable only at higher reservoir levels (at lower reservoir levels, the generation capacity is about half that amount). The power plant can be operated at flows ranging from 200 cfs to 1,200 cfs (Cooper 2019). Abiquiu's generators have a nameplate capacity of 16.8 MW (Cummins 2018).

1.2. Study Aims and Methods

This study is a pilot project funded by Reclamation. It examines 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 project emphasizes the portion of the river affected by Reclamation's reservoir operations at El Vado Dam, so does not consider the reach below Abiquiu Dam, which is owned and operated by the U.S. Army Corps of Engineers (USACE). This project also identifies areas where further research is warranted and proposes a plan for future site-specific data collection.

The project uses a combination of economic and hydrologic modeling to calculate an economic value for Rio Chama water under baseline model conditions. We then model the economic impacts of change scenarios suggested by Reclamation and other members of the team developing this reservoir operations pilot study. The economic values produced in these scenarios are evaluated both on their overall economic impacts and on the outcomes expected in the economically vulnerable rural area surrounding the river. This allows consideration of equity issues that can otherwise be obscured by benefit-cost analysis (Polasky and Binder 2012). The study also notes the areas where data are unavailable or ambiguous.

The economic impacts of the El Vado-Rio Chama system include:

- 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. This analysis uses a system dynamics model with a baseline daily timestep and hourly sub-modeling for hydroelectricity. It does not incorporate long-term or multi-year impacts.

The study develops a cost-benefit framework incorporating dimensions of value associated with the Rio Chama: the reservoirs' recreational value, recreational value associated with the river reach below El Vado Dam, the ecosystem services value of the area, and hydropower's market value. In addition, we also estimate indirect economic impact of recreational tourism in the area. We discuss but do not model the value of hydropower generation's impact on availability of intermittent renewable electricity. Values are based on benefit transfers from existing river and ecosystem research and incorporated into the system model. All dollar amounts are in 2017 constant dollars

We use revealed preference data collected in the Rio Chama area in the 1980s and 1990s and modified it to reflect the area's changing population and economy to calculate recreational values (Booker and Ward 1999 and Ward 1987). A benefit transfer from Weber and Stewart (2009) provides a lower bound for ecosystem services values. Hydropower valuation is based on real-time market prices for wholesale power published by the California Independent System Operator.

The river system is modeled in GoldSim software to produce a Monte Carlo simulation. The result is a predicted range of values associated with changes in Rio Chama management, based on stochastic modeling of rainfall, evaporation, water flow, and electricity prices.

1.3. Outcomes

An analysis of the economic value of Rio Chama water flow, as modeled, indicates the highest value use is recreational. Our results are provided in . The values include probability levels from the stochastic modeling. The river reach and the reservoir provide the majority of value associated with the Rio Chama above Abiquiu, and the indirect economic impact of tourism is also substantial.

Table 1. Values of Non-Consumptive Water Use on the Rio Chama

	Minimum	25	50	75	Maximum
Hydro revenues	$ 841,471	$964,846	$1,012,011	$1,054,888	$1,234,901
Hourly submodel	*$968,147*	*$1,098,719*	*$1,147,743*	*$1,193,635*	*$1,382,997*
Reach recreation	$2,438,686	$3,396,264	$3,650,262	$3,888,874	$4,922,242
Reservoir recreation*	$17,083,960	$19,050,770	$19,486,330	$19,768,330	$20,123,620
Minimum	*$4,783,242*	*$5,333,918*	*$5,455,868*	*$5,534,824*	*$5,634,299*
High	*$54,724,740*	*$61,024,980*	*$62,420,200*	*$63,323,530*	*$64,461,620*
Ecosystem services	$0	$47,791	$47,791	$103,344	$243,711
Indirect value of tourism	$1,911,420	$2,101,654	$2,138,315	$2,168,013	$2,269,289
Total	$22,275,537	$25,561,325	$26,334,709	$26,983,449	$28,793,763

*Reservoir recreation values depend on flow levels.

Scenario analysis indicates that maintaining water flow at minimum rafting levels through summer weekends has a net economic benefit, despite some negative impact on reservoir recreation. We also find that retaining water at Heron Reservoir has net negative impacts for the study area, but provides substantial economic benefits when Heron Reservoir recreational values are incorporated. We note that existing data do not adequately characterize the economic impacts of a low-water scenario at Heron Reservoir.

The remainder of this report is organized as follows:

- Section 2 reviews interdisciplinary system analysis, economic valuation methodologies, and benefit transfer.
- Section 3 explains the modeling used in the analysis.
- Sections 4 through 7 discuss the valuation methodology used for each direct dimension of value associated with the system.
- Sections 8 and 9 discuss the valuation of indirect impacts.
- Section 10 discusses model outcomes for the proposed change scenarios.
- Section 11 examines flow requirements for a blue-ribbon tailwater fishery.
- Section 12 discusses conclusions, caveats, generalizability, and further research.

2. Evaluation Methodology

Economic cost-benefit analysis is complicated by the characteristics of the Rio Chama system. The river is highly engineered, with multiple human-made reservoirs, water flows augmented by imports from the Colorado River Basin (San Juan Chama Project water), and dams controlling flow. The complexity of the physical structure is echoed by the interlocking statutory and management structures that constrain water flow decisions (Utton 2015). The river's natural cycles both respond to human governance and dictate the terms of river management as weather and ecosystems change.

Interconnected systems like engineered rivers have been described as coupled human and natural systems (CHANS) (Liu et al. 2007). CHANS are characterized by complex spatial, temporal, and organizational interactions with feedback effects. Managing these systems requires awareness of the direct and indirect impacts of decision-making over time. In many CHANS, the timeframes involved can range from the minute-to-minute commodity market price changes to ecosystem impacts that may not be manifest for years or decades.

Because of the complexity of these systems, hydro-economic modeling is a valuable tool for water management decisions (Furqan Khan et al. 2017, Harou et al. 2009, and Heinz et al. 2007). Incorporating economic, engineering, and hydrologic information into a dynamic model captures the impact of socio-economic changes over time. This allows a successful simulation to reflect feedback effects and trade-offs over many periods, reducing the likelihood of unanticipated negative outcomes (Cavender-Bares et al. 2015). However, such modeling requires simplification of multifaceted processes and dimensions of value. Reducing complex system characteristics to financial terms allows comparison between impacts of disparate types but carries the risk of oversimplification.

Some valuation methods for environmental system characteristics are imprecise. However, the outcomes are still important to incorporate into policy evaluation, so long as their limitations are recognized (Brown et al. 2007). Hanley (1995) observes that cost-benefit analysis incorporating environmental valuation is not sufficient as a stand-alone tool to evaluate policy issues—ultimately, some dimensions of value may not be quantifiable, and policymakers should consider these dimensions as well. In this document, we note areas where we believe this hydro-economic model does not adequately capture values associated with Rio Chama flows.

2.1. Market and Non-Market Values

Valuing commodities that are bought and sold is relatively straightforward. Dimensions of value that can be quantified by price are considered market values. Values are set when a sale takes place, or when a market exists for a comparable item (e.g., electricity production from El Vado Dam is consumed by the dam's operator, Los Alamos County, rather than being sold on the open market). In this study, the value is the price offered for electricity at the nearby Four Corners hub.

Non-market values are dimensions of value that have no simple price attached to them. They can include benefits that cannot be sold or purchased, such as the "outstandingly remarkable" scenery preserved by the Wild and Scenic Rivers Act (Wild and Scenic Rivers Act 1968[1]).

Non-market values can be divided into use and non-use values (Brown et al. 2007). A visitor's use value for a reservoir might be the amount she would be willing to pay to spend a day kayaking there. This cannot be represented by access fees alone: visitors have also invested time and money in travel to the site. Use values vary by person, because willingness to pay for an experience reflects an individual's unique tastes and preferences.

Non-use values include option and existence values (Krutilla 1967). An individual who has never rafted down the Rio Chama might be willing to pay some amount of money to preserve the option of rafting through the canyon next year. Another person might not anticipate ever visiting the Rio Chama but might still be willing to pay some amount of money to preserve its ecosystem for present or future generations.

These dimensions of value are not easy to capture, but they are clearly non-zero. In addition to the Federal Wild and Scenic River designation, New Mexico has created state parks around the reservoirs, and a private entity, Birdlife International (partnered with the National Audubon Society), has named the river canyon an Important Bird Area (Audubon n.d.). Each of these designations required a group of private citizens to value the area's existence enough to request formal conservation action, but there is no clear way to quantify that value (Madariaga and McConnell 1987). Any process for estimating an area's ecosystem services value must consider such unquantifiable characteristics.

2.2. Travel Cost Method and Contingent Valuation Method

Brown et al. (2007) provides an overview of the ways in which non-market values can be measured. Methods of determining non-market values can be separated into revealed preference methods and stated preference methods. Revealed preference valuation methods use individuals' observed behaviors with respect to market goods, such as hotel rooms or entrance fees, to extrapolate the value of a non-market good, such as a visit to a national park. Stated preference methods ask a sample of the population about their willingness to pay for a good. Since non-use attributes of environmental goods do not have economic actions associated with them, they must be valued using stated preference methods.

The revealed preference method used in this study is the travel cost method, in which the cost of traveling to and participating in a recreational activity is collected from a sample of visitors and used to construct a representative demand curve for the activity. The researcher collects travel information from individuals who live at differing distances from the site and examines how visitation behavior changes as distance from the site varies. Because the implicit cost of the visit varies by distance from the site, this can be used to derive the demand for the activity at differing price points (Loomis 2000). This method was first suggested by Hotelling in 1956 and further

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[1] Wild and Scenic Rivers, Public Law (P.L.) No. 90–542 (1968). 16 U.S.C. 1271: §1(b), 82 Stat. 906. Retrieved from https://www.law.cornell.edu/uscode/text/16/1271.

expanded by Clawson and Knetsch in 1966 (Clawson and Knetsch 1966 and Hanemann 2006). Brown and Mendelsohn (1984) adapted the method to value qualities of recreational areas as well as specific locations. It has been widely used in economic valuation, sometimes combined with a stated preference component (Loomis and McTernan 2014).

Stated preference methods have the advantage of capturing both use and non-use values, in contrast to revealed preference methods. This may be preferred to the travel cost method even for use values, particularly when the process of data collection for the travel cost method is impractical (Cropper and Oates 1992).

Contingent valuation (CVM) is a stated preference method frequently used in environmental valuation. This method, originally proposed by Ciriacy-Wantrup in 1947, consists of creating a hypothetical market by surveying a sample group and eliciting their willingness to pay to acquire a public good (Carson 2012). They may instead be asked the minimum amount they would be willing to accept as compensation for losing a public good, although the difficulty of framing such a loss in a plausible way makes willingness-to-accept a less popular method in the survey literature. The survey must describe the good being provided, its context, and the means of financing it. The survey-takers are then asked whether they would vote for the provision of this good in a referendum context if it cost them a certain amount. Different costs are offered to different survey takers, which again allows the researcher to derive demand for the good at various price points (Loomis 2000). (Alternatively, they may be asked to name the maximum payment amount at which they would support a referendum providing the good.) Regression models are used to estimate a mean or median willingness to pay for the good.

The quality of this information depends heavily on the quality of the survey and its plausibility and significance to survey-takers. The more specific and thorough the information provided to survey-takers, the higher a valuation they provide for the environmental good (Hanley 1995). After a contingent valuation survey was used to assess non-market damages in the 1989 Exxon Valdez oil spill, the method came under considerable industry criticism for its potential biases. A blue-ribbon panel appointed by the National Oceanic and Atmospheric Administration (NOAA) evaluated the method and enumerated its best practices and limitations (Arrow et al. 1993). The NOAA panel recommends providing as much information as possible in an easy-to-understand form, offering a close-ended rather than open-ended valuation question (e.g., “Would you pay $5.00 for this good?” rather than “What is the most you would be willing to pay for the good?”), reminding the respondent of the constraints of his or her budget, and avoiding generalities or implausible mechanisms that might provoke skepticism on the part of respondents. Even with these best practices, the NOAA panel concluded that willingness to pay based on contingent valuation surveys is likely to be overestimated.

Contingent valuation surveys can be validated through other means. They generally successfully predict referendum outcomes (Carson 2012). In some studies, CVM shows values similar to but somewhat smaller than travel cost method evaluation (Carson 2012 and Ferrini et al. 2014). They are commonly used in water resources policy decisions related to dam management (Loomis 2000).

2.3. Benefit Transfer Uses and Limitations

Benefit transfer is the practice of using existing research to extrapolate non-market values for a new study area. This is a far faster and less expensive process than undertaking non-market valuation in a new context, and it can be used to inform study objectives if later primary study data collection is planned. Because of the cost savings from benefit transfers, government organizations such as the U.S. Forest Service, U.S. Environmental Protection Agency, Bureau of Land Management (BLM), and USACE have formal frameworks to be used in the benefit transfer process (Boyle and Bergstrom 1992, Richardson et al. 2015, and Rosenberger and Johnston 2009).

Boyle and Bergstrom (1992) outline a conceptual framework for benefit transfer. They suggest that the study start with a theoretical framework for the non-market attribute to be valued. Existing studies of similar valuation at other sites are then collected and compared. The transferability of existing studies is analyzed to determine whether the commodity valued is the same between the sites in question, whether the populations affected have the same characteristics, and whether the property-right structure at the sites is identical (to determine whether willingness-to-pay or willingness-to-accept is the appropriate valuation measure). The quality of appropriate existing studies is examined for bias. Then the values are systematically adjusted to compensate for differences between the sites that may bias results.

A single-study benefit transfer must be conducted with care—since errors in the original research will be magnified by the transfer process (Brookshire and Neill 1992). To reduce the likelihood of error, benefit transfer is sometimes conducted using a meta-analysis of existing studies with potential applicability to the primary site (Bergstrom and Taylor 2006, Rosenberger and Johnston, 2009, and Johnston and Rosenberger 2010). This approach has the advantage of incorporating many different estimations, reducing the probability of a single researcher's error being propagated into the new valuation estimate. However, two major concerns preclude the use of meta-analysis in this case:

- **The difficulty of finding comparable studies.** The Rio Chama is a relatively small river with a relatively small hydroelectric and recreational value. Primary research is biased toward larger sites, which attract more research funding (Ros enberger and Johnston 2009). This research priority bias limits the applicable studies available for use, and site similarity is critical for accurate benefit transfer results.

- **Meta-analysis results in an opaque statistical transformation of many different studies** (Bergstrom and Taylor 2006). There is no defined protocol established for all benefit transfer meta-analyses. Instead, the process of meta-analysis requires the researcher to use his or her own judgment and experience to adjust for the heterogeneity of research sites and research methods, which can introduce significant generalization error (Johnston and Rosenberger 2010 and Kaul et al. 2013). When benefit transfer values are incorporated into a system dynamics model like the one used for this study, the modeling framework may potentially amplify and obscure any error in a meta-analysis.

Instead, we used a simple transformation of the closest applicable existing study in our benefit transfers. This increases the potential for error resulting from measurement error in the original study but decreases the potential of error from site dissimilarity or generalization error. The derived value was then compared with values obtained from other existing studies. This approach prioritizes transparency of data generation, which is of paramount importance in system dynamics modeling (Winz et al. 2009).

The benefit transfer process has been criticized as inadequate to value intricate environmental systems. Because dam impacts are so complex, some research suggests that the benefit transfer process is not adequate to evaluate them (Botelho et al. 2017). Botelho and co-authors suggest that cost-benefit analyses of proposed hydropower installations be informed by site-specific valuation surveys rather than relying on the adaptation of existing research.

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. However, despite the dearth of contemporaneous local research, the benefit transfer process provides a method to quantify non-market values associated with Rio Chama flow patterns accurately enough to provide insight into the trade-offs associated with river flow changes (Richardson et al. 2015).

3. Model

The reservoir-dam-river system is represented using a system dynamic model centered on El Vado Dam, in which dimensions of value are functions of flow through the dam, water stock in the reservoir, or both. El Vado Reservoir's volume increases over time as a function of inflows from the upper Rio Chama, inflows of San Juan-Chama water from Heron Reservoir, and precipitation. It decreases as a function of outflows at the dam and evaporation. Downstream river conditions are a function of dam outflow, as is the water stock in Abiquiu Reservoir.

As water flows through the system, it drives more than one dimension of value. Flow decisions transfer water from one use (e.g., reservoir recreation) to another (e.g., hydropower generation and rafting.) Ward and Lynch (1997) argue that, if uses are closely interdependent and water flow is non-consumptive, as is the case in this segment of the Rio Chama, the overall economic value of the system is relatively stable despite trade-offs between value dimensions.

However, Ward and Lynch's framework omits consideration of ecosystem services. Hanley (1995) identifies the interaction of ecological and economic systems as a potential source of destabilizing feedback within such models. The modeling framework we propose incorporates natural system impacts as well as human value drivers.

3.1. Hydrologic Model

The hydrologic model underpinning this economic valuation model is developed by Morrison and Stone (Benson et al. 2013, Morrison 2014, and Morrison and Stone 2015a and b). Morrison and Stone used GoldSim system dynamics modeling software to model hydrological changes in the Rio Chama between El Vado and Abiquiu Reservoirs over a 365-day period. The authors used probabilities based on historical time series data to model precipitation, evaporation, inflow from the upper Rio Chama, and San Juan-Chama Project water deliveries. They then model expected hydropower, rafting, and ecological outcomes.

Morrison and Stone's primary focus is to apply probabilistic system dynamics modeling to incorporate system feedback and evaluate trade-offs between flow scenarios. Rather than attempting to optimize a specific ecological process, the authors take four flow scenarios recommended by ecological experts familiar with the Rio Chama and examine the hydrological outcomes under each recommended scenario. The recommended flow patterns include a series of occasional flood events and a baseline flow regime over the winter and spring months to prevent disruption during the brown trout spawning season.

The model was first used to determine whether the alternative flow patterns provide adequate physical conditions for cottonwood seedlings to root, and how they affect reservoir storage (Morrison and Stone 2015b). The model is extended to reflect rafting and hydropower impacts resulting from the four proposed alternative flow regimes, and Morrison and Stone (2015a) calculate mean monthly hydropower output under the four alternatives, as well as the average number of rafting days available.

3.2. Economic Model

The economic valuation model we developed uses Morrison and Stone's framework within GoldSim system dynamics software to generate daily flow- and reservoir-dependent economic values summed over a 1-year period (GoldSim Technology Group 2018).

There is no substantive consumptive water use between El Vado Reservoir and Abiquiu Reservoir, so only values associated with non-consumptive use are incorporated into the model. El Vado Reservoir and Heron Reservoir provide recreational boating, fishing, and camping, while the dam itself provides electricity and the river reach below the dam provides recreational rafting, fishing, and camping. The river reach also provides ecosystem services, including habitat for both native and non-native species in the Wild and Scenic reach. This ecosystem meets the definition of a novel ecosystem proposed by Morse et al. (2014): 1) origins in human agency; 2) crossed ecological thresholds; 3) altered species composition; and 4) capacity to sustain itself.

Changes in the amount of water in El Vado Reservoir directly impact the number of visitors coming to El Vado Reservoir and the amount of power generated by a given release through the El Vado generator (Cooper 2019). Changes in the water discharges out of El Vado Dam directly affect the amount of power generated, the value of recreational rafting and fishing downstream of the dam, and the health of the riverine ecosystem and, therefore, the ecosystem service value derived from the river reach.

Reach recreation is modeled as a function of time of year and daily flow in cfs. Reservoir recreation is modeled as a function of time of year and reservoir height. Power generation is modeled as a function of daily flow and reservoir height.

Recreational visits to the reservoir and the river reach have indirect economic impacts on the surrounding community, as visitors purchase food, gas, lodging, or other goods in rural Rio Arriba County. The use of hydropower has indirect ecological impacts, since zero-carbon hydropower generation displaces electricity generated with fossil fuels. Timed hydropower generation can support access to renewable energy from solar or wind sources, further indirectly reducing carbon emissions.

The analysis of the indirect economic impact of recreation uses the information generated from the reach and recreational visits coupled with economic data from Impact Analysis for Planning (IMPLAN). This is a professional economic impact analysis software widely used to perform economic contribution analyses. Its data are taken from Federal and regional databases. The ecological impacts of hydropower are discussed, but there are insufficient data to adequately quantify them as a function of reservoir stock or river flow. Figure 1 shows the interactions within the economic model. Interactions are both direct and indirect:

- **Direct impacts:** Reservoir stock drives reservoir recreation and ecosystem services values. Reservoir stock and water flow through the dam affect hydroelectric generation values. Waterflow below the reservoir affects reach recreation and ecosystem services values.
- **Indirect impacts:** Reservoir and reach recreation have local economic impacts, and hydroelectric generation availability affects the amount of intermittent renewable energy

that can be incorporated onto the grid and the level of greenhouse gas emissions that would otherwise be emitted.

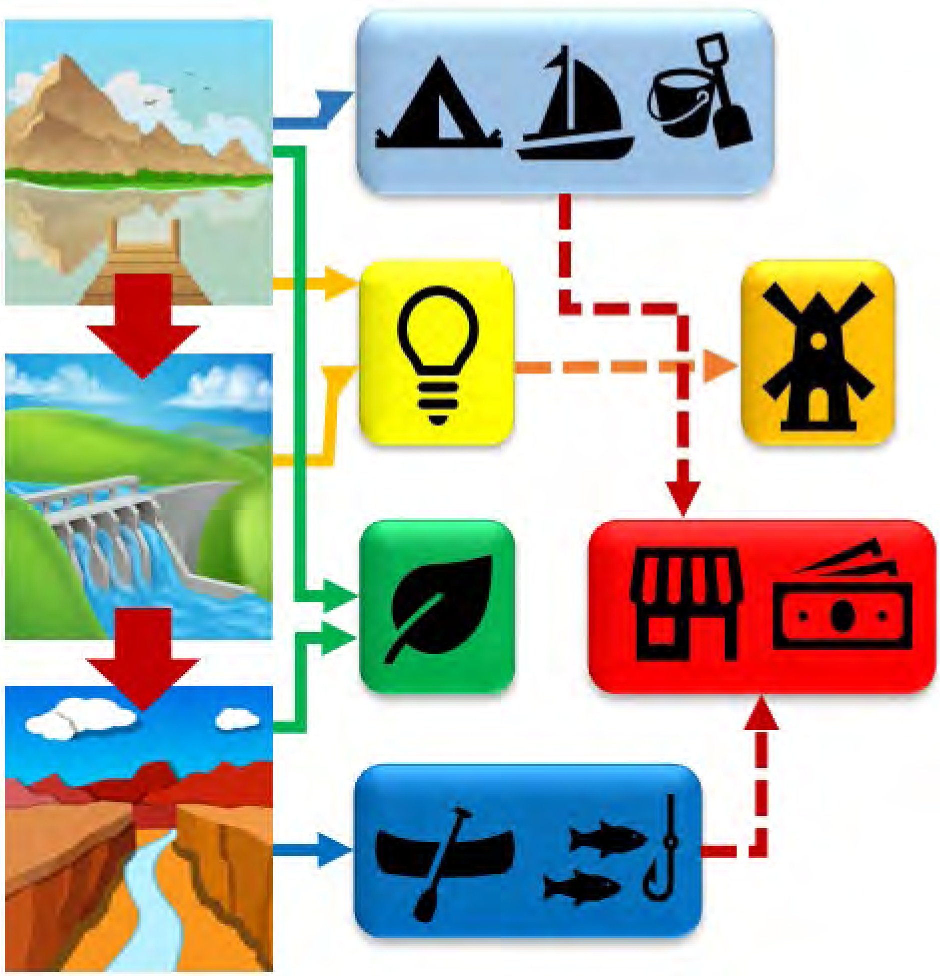

Figure 2. Interactions within the economic model.

3.3. Limitations

This analysis is limited to a probabilistic model of a single year; the model does not incorporate economic impacts arising over multiple years. Sustained multi-year flow changes affecting recreational values may result in larger long-term indirect economic impacts than those calculated in the model, due to factors such as increased capital investment in the community.

The model incorporates some longer-term environmental impacts such as riparian vegetation recruitment. However, it does not take into account potential non-linear impacts of flow or water quality (including turbidity) on the river ecosystem, which could increase vulnerability to tipping-point or threshold events that might permanently disrupt key species (Cavender-Bares et al. 2015). Fish and macroinvertebrate data (see Harvey 2022 [Attachment] associated with this economic analysis) suggest that such changes have already occurred in this ecosystem. Such non-linear changes can significantly affect the value of ecosystem services, but modeling them would require more data related to ecosystem outcomes (Brock and Carpenter 2006 and Pace et al. 2015). Further research should examine potential ecological tipping points within the Rio Chama system.

The hydrological model incorporates El Vado Reservoir, the Rio Chama below El Vado Dam, and Abiquiu Reservoir. Because Heron Reservoir is not modeled within the system, its economic impacts are omitted (except in the scenario that examines changing the dock level at Heron Reservoir). Abiquiu Reservoir's economic impact is not considered. If recreational visits to El Vado Reservoir and Abiquiu Reservoir can be substituted for one another, flow decisions that decrease (or increase) El Vado Reservoir visits may increase (or decrease) Abiquiu Reservoir visits—overestimating the absolute economic impact of reservoir recreation changes.

Assumptions and benefit transfers are deliberately conservative, since the modeling process can magnify errors (Boyle and Bergstrom 1992). Unless otherwise noted, the values provided should be assumed to be a lower bound of the potential economic impacts of flow changes in the Rio Chama system.

4. Market Values: Hydroelectric Power

Economic valuation of hydroelectric power is straightforward. The quantity of generated power is easy to measure, and electricity prices are publicly available. However, power prices can vary significantly over time. Because of the high cost of electricity storage, power is usually consumed as it is produced. Power demand changes throughout the day, often peaking in the evening hours. Supply and demand must be balanced in order to prevent damage to grid infrastructure, so prices can vary dramatically over a 24-hour period. Retail distributors generally charge a fixed price per kilowatt-hour that smooths intraday price spikes, but wholesale pricing does reflect intraday time-dependent price changes. Consequently, we use wholesale prices for this analysis.

The baseline model uses a stochastic model of average daily price during a given month to examine hydroelectric values, since flows are generally maintained at the same level for at least 24 hours. We also include an hourly sub-model illustrating potential impacts of intraday flow changes designed to increase generation at times of day with higher power prices.

4.1. Current Equipment and Management

El Vado Dam is equipped with a two-turbine generator that is formally rated as an 8.0 MW run-of-the-river unit by the Federal Energy Regulatory Commission (FERC) (FERC 2011). Los Alamos County considers this generator to have a capacity of 8.8 MW, including the 10 percent leeway allowed by the license, and the generator actually produces up to 10 MW under normal operating conditions (Cummins 2018). The dam's efficiency ranges between 84 percent and 93.5 percent, with greater efficiency at higher outflows. It cannot generate power at less than 180 cfs. The maximum turbine throughflow is 1,320 cfs, so water releases in excess of this amount bypass the generator and produce no additional energy. The transformer attached to the dam has limited capacity, so Los Alamos County does not permit instantaneous generation to exceed 10 MW (Cummins 2018).

LACDPU has a 24-hour operations center that manages its power infrastructure. The power dispatcher can change flows out of El Vado Dam remotely from the control room. These changes are made in accordance with Reclamation instructions, and LACDPU does not actively manage water flows as a way to alter power generation. Since the operation center is staffed 24 hours per day, flow changes are essentially costless—they would require no additional staffing or equipment and could be performed using an existing supervisory control and data acquisition system (Benson et al. 2013).

4.2. Pricing and Valuation

The hydroelectric power produced by El Vado Dam is consumed by Los Alamos County and Los Alamos National Laboratory. Its value can be approximated using the purchase price of power at the closest wholesale power hub, Four Corners. Since October 2016, the Four Corners hub has been associated with the California Independent System Operator's external energy imbalance market, which provides publicly available real-time power prices every 5 minutes.

During 2017-2018, average prices were significantly higher and more volatile on weekdays than on weekends. Power prices were highest in July and August and lowest between March and June. Summer prices may reflect air-conditioning needs, while winter prices may reflect greater need for artificial lighting due to a short solar day or some reliance on heating units powered by electricity.

Hourly power prices were highest between 5 and 9 p.m. and lowest between 10 a.m. and 2 p.m. Low midday hourly prices reflect low-cost solar power in the Southwest displacing more expensive generation, and high evening prices are a result of greater evening consumer demand as solar generation falls to zero and evening power use increases.

Water flow and power generation at El Vado Dam peaks in the spring runoff season, a period of relatively low power prices. Los Alamos County's power demand peaks in the evening, but dam generation is consistent throughout the day and does not respond to increased electricity demand hours (Cummins 2018). Optimizing the value of the power generation at El Vado would require water-flow management that increased flows during higher-value hours and seasons.

4.3. Model Framework

Hydropower generation (G_t) is a function of turbine efficiency (C_{ef}), gravity (g), water density (ρ), reservoir height or head ($H_t(R)$), which is a function of reservoir volume R, and water flow (Q_t) as shown in Equation 1:

$$G_t = C_{ef} \rho g H_t(R) Q_t \qquad (1)$$

Reservoir head is a function of reservoir volume, and this is modeled through a storage-stage conversion table. Flows less than 180 cfs are treated as zero, and flows greater than 1,320 cfs are treated as 1,320 cfs. Power generation greater than 9 MW is truncated to reflect the transformer's technical limit.

Prices are derived from a stochastic price model. Average monthly power prices and their standard deviations are calculated from California Independent System Operator price data at the Four Corners hub from October 1, 2016, through September 30, 2018. These prices are used to construct a normally distributed price model. The simulation software uses this model to generate daily prices. The 1,000-simulation Monte Carlo model produces a probability distribution for the value of power generated. All results are reported in 2017 constant dollars.

Under the baseline flow assumption, in which hydroelectric prices are ignored and reservoir release decisions do not incorporate hydropower generation considerations, daily energy production can range between 0 and 240 megawatt hours (MWh), with an average daily production of 42.59 MWh. Assuming flows that do not have substantial intraday changes, this results in average yearly power values between $841,471 and $1,234,901.

4.4. Ancillary Services

To maintain the stability of the area's power grid, Public Service Company of New Mexico (PNM), the local Balancing Authority Area operator, requires utilities to directly provide or purchase ancillary services. These services include spinning reserves, which is generation with the ability to instantaneously increase and decrease power production in response to signals from the grid operator, and non-spinning reserves, which have 15 minutes to increase or decrease power. Los Alamos County currently purchases spinning and non-spinning reserves from PNM for more than $1 million annually (Pace Global 2017). If LACDPU were permitted limited freedom for dispatching water through El Vado Dam, it could provide some portion of these spinning reserves itself. At most water levels, a change up or down of 100 cfs provides approximately 1 MW of power, 20 percent of LACDPU's spinning reserve requirements. This flexibility is worth approximately $8,000 per month, in addition to the market value of the power produced (Cummins 2018).

4.5. Peak Power Production Submodel

The base model assumes that the minimum dam-release change increment is 1 day, but ignoring hourly fluctuations in power prices neglects a potential source of value. Increasing evening releases to capture higher power prices is a common practice for hydroelectric generators selling into a power market. This submodel is presented as a simplified example of the possible increase in hydroelectric value that could be derived from permitting intraday flow variation without changing total daily outflow from the dam.

In theory, a system dynamics model with two disparate timesteps can be optimized by reducing the solutions into a single dynamic model in the slower timestep (Grimsrud and Huffaker 2006). We used a simpler transformation, since our model measures economic outcomes but does not attempt to mathematically optimize them. We instead compared model outcomes for a constant 24-hour flow level with model outcomes under a daily maximization pattern in which flows are highest during highest-price hours. This pattern is defined by a set of arbitrary pattern rules intended to reflect potential water management constraints, including ecological concerns and downstream water requirements. This submodel calculates the average increase in hydropower value associated with the maximization pattern for a given month and daily turbine throughflow. The rules are:

Rule 1: The total water passed through the dam in a 24-hour period remains constant.
Rule 2: Water flow increments up or down every hour, on the hour, by no more than 10 percent.
Rule 3: Weekend flows are unchanged.

Rule 1 simplifies the comparison between base model and submodel outcomes. It also reflects the reality that the requests from water rights owners limit hydropower-maximizing flow changes and ultimately determine when water is released through El Vado Dam. Greater flexibility of water delivery requirements might allow some relaxation of Rule 1.

Rule 2 reflects ecological considerations that should impact peak power production decisions. Literature examining the impact of intraday flow changes at hydroelectric dams finds a variety of negative impacts on river habitat and reproductive outcomes for native fish and insects

(Harpman 1999, Moog 1993, and Poff and Schmidt 2016). These impacts vary across rivers and species. Seasonal monsoon rainstorms may result in more varied summer intraday flow patterns in undammed New Mexico rivers. Determining a maximum acceptable intraday change rate for the Rio Chama is an ecological question outside the capabilities of this model.

The submodel uses an arbitrary maximum hourly change value of 10 percent for illustration purposes. Based on the downstream gage measuring water flow out of the El Vado Dam from 2007 to 2018, releases from the dam may change by as much as 600 cfs over a 15-minute period (U.S. Geological Survey [USGS] 2018). Such significant flow changes are infrequent occurrences, and most intraday release changes are less than 20 cfs. This submodel does not attempt to change the impact of between-day flow changes, nor does it attempt to model seasonal variations in appropriate maximum hourly water release change.

Rule 3 reflects the current policy that prioritizes recreational rafting flows over summer weekends. To prevent interaction with reach recreation values, no weekend intraday flow changes are modeled. This reflects two other considerations, as well. Since electricity price peaks are significantly lower over the weekend, weekend intraday price optimization is less valuable. Furthermore, avoiding intraday waterflow changes over the weekend may improve riverine insect reproductive outcomes (Poff and Schmidt 2016).

Increasing dam releases through the power plant during evening hours and decreasing it at other times has an unambiguously positive effect on hydroelectric value. Unsurprisingly, this effect is largest in summer months, when power prices are high, and when flows are between 450 and 900 cfs. At average daily releases greater than 900 cfs, intraday flow modifications become less advantageous because the maximum useful turbine outflow is 1,320 cfs.

This submodel (see Table 2 and Table 3) serves as a proof of concept only. A similar submodel could be built to reflect other management rubrics, as required. We expect that any ecological constraints imposed on peak power production would include seasonal as well as daily constraints to reflect Rio-Chama-specific recreational use and fish spawning patterns.

Table 2. Hydroelectric Intraday Maximization Submodel Outcomes by Month

Month	Value Increase
January	3%
February	7.3%
March	4.8%
April	9.1%
May	9.4%
June	9.5%
July	10.6%
August	10.4%
September	8.0%
October	7.8%
November	3.5%
December	3.1%

Table 3. Hydroelectric Intraday Maximization Submodel Outcomes by Flow

Flow	Value Increase
<300 cfs	none
300-450 cfs	7.5%
450-950 cfs	9.4%
950-1,150 cfs	6.2%
1,150-1,320 cfs	1.8%
>1,320 cfs	none

When intraday flow changes are used to increase generation during peak power times, the model shows a value increase of approximately 4 percent. If this were combined with the flexibility necessary to allow LACDPU to use El Vado hydropower to cover some of its spinning reserves requirements, the value of water releases through the dam increases by an average of 13 percent.

4.6. Assumptions and Limitations

The model assumes that the generator at El Vado Dam has no market power at the Four Corners hub. Given that combined generation capacity of the nearby coal-powered Four Corners Generating Station is 1,540 MW, about 171 times greater than El Vado's maximum capacity, it is highly unlikely that a 9 MW increase or decrease in generation would affect power prices.

The model assumes that there is no correlation between water inflow, water evaporation, and power prices. This assumption may not be correct under all circumstances. In a situation with unusually high or low rainfall in the Western United States, it is possible that power prices could be influenced by water levels in large reservoirs (e.g., Lake Mead and Lake Powell), since the large Western Area Power Authority dams provide a significant amount of energy to area electricity markets. Likewise, higher temperatures might increase both evaporation and electricity demand for air conditioning. Either case would result in correlation between reservoir head and prices. This potential interaction is not modeled, and prices are treated as developed from external factors.

5. Reach Recreation

Fishing and rafting are the primary value drivers for reach recreation in the Rio Chama downstream of El Vado Dam. The quality of recreation available for both rafting and fishing is dependent on the reservoir release schedule over the course of the year, including during the time that the recreation occurs, as well as at key periods in the ecological cycle, such as the brown trout spawning period. We derived use values for both activities using benefit transfer from a travel cost analysis of the Rio Chama performed in Daubert and Young (1981).

The baseline model uses transformed valuation numbers associated with weekend rafting and fishing during the summer. This omits values associated with weekday recreation and with fishing use over non-summer months. Since autumn fishing includes high-value brown trout angling, it is probable that this results in a significant downward bias of overall recreational value associated with fishing in the Rio Chama. However, there are limited data on the ways in which flow changes during the year affect autumn sport fishing. This issue is discussed further in the examination of the blue ribbon tailwater fishery scenario in Section 10.4.

5.1. River Recreation Literature

There is a wide array of literature related to river recreation valuation, but few studies directly linking reservoir releases or flow in the river to recreational value.

Ward (1987) uses the travel cost method (TCM) to determine fishing and rafting benefits within the study area. Ward conducted in-person interviews of 338 recreational visitors to the Rio Chama reach downstream from El Vado Dam over the summer of 1982. The researcher showed color photographs of different streamflow levels to the participants, who were asked to provide their preferred level of river recreation at a given streamflow. Travel costs are calculated based on distance traveled, length of stay, and income. Values are calculated both for anglers and for rafters. Ward's surveying includes only the months of May through August and does not include autumn trout anglers or streamside recreation. Ward predicts streamflow values for a range of flows between 50 cfs and 4,000 cfs. Currently, there is rafting at flows of 500 cfs, although multi-day trips are limited to flows below 600 cfs.

Table 4 shows Rio Chama flows by month.

Table 4. River Water Flow Comparison Table (average monthly cfs)

River	USGS Gage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rio Chama	8285500	146	153	274	750	1380	770	459	439	390	218	190	274
Cache la Poudre	6752260	34	34	36	94	501	905	226	83	73	52	34	31
Big Hole	6024580	197	231	318	1390	2760	3120	960	299	208	267	264	257
Bitterroot	12350250	480	446	1110	1920	4340	5300	1280	392	404	562	1150	781

Studies on other rivers include:

- Daubert and Young (1981) write an early and influential paper in which they use contingent valuation (CVM) to estimate flow values in the Cache la Poudre River in Colorado. These values are associated with fishing, rafting, and streamside recreation. Cache la Poudre River is a popular recreational river with average discharge about 30 percent of the Rio Chama's flows.[2] It is also a designated Wild and Scenic River. Daubert and Young (1981) also find that streamside recreation has little response to stream discharge, while fishing value peaks around 500 cfs and decreases thereafter, and rafting value increases up to a flow value of 1,150 cfs. They derive a maximum visit value of $30.85[3] for anglers (for a flow of 500 cfs) but do not report rafting values.
- Duffield et al. (1992) use CVM to examine recreational benefits of instream flows in the Bitterroot and Big Hole Rivers in Montana. They derive per-day values for residents of between $50 and $70, and between $90 and $110 on the Bitterroot River. Value on the Big Hole River ranged between $165 and $215.[4] They report value changes over a range of flows between 100 and 2,000 cfs.
- Loomis and McTernan (2014) also examine whitewater rafting on Cache la Poudre River, using both TCM and CVM. They report rafting values for non-commercial rafters at discharge flows ranging between 300 and 2,300 cfs, with a per-trip value around $100 using both TCM and CVM. This is the most recent rafting valuation data available in the literature. However, the Cache la Poudre River offers day-rafting only, whereas the Wild and Scenic Reach of the Rio Chama offers both day rafting and multi-day trips, so only limited comparisons can be made between these two systems.

5.2. Benefit Transfer for Use Values and Model Framework

Commodity consistency is key to accurate benefit transfer (Johnston and Rosenberger 2010). Because we use a single-study unit value transfer to evaluate reach recreation values, it is particularly important that the site, the population, and the good value match as closely as possible (Kaul et al. 2013). We therefore used the Ward (1987) study to derive current values for Rio Chama reach recreation (Table 5 and Table 6). Ward's survey work was performed in 1982, so the necessary transfer is over time, rather than location.

[2] calculated from average flow data at USGS gages 08285500 and 06752260

[3] 1981 dollars

[4] 1992 dollars

Table 5. 2017 Annual and Daily Benefits Adjusted for Population and Inflation

	Annual Benefits			Benefits Per Day		
Flow (cfs)	**Fishing**	**Rafting**	**Sum**	**Fishing**	**Rafting**	**Sum**
50	$1,118,527.79	$0	$1,118,527.79	$16,947.39	$0	$16,947.39
100	$1,494,400.84	$0	$1,494,400.84	$22,642.44	$0	$22,642.44
250	$1,640,767.97	$0	$1,640,767.97	$24,860.12	$0	$24,860.12
500	$2,056,144.02	$0	$2,056,144.02	$31,153.70	$0	$31,153.70
1,000	$1,616,409.81	$3,811,725.21	$5,428,135.02	$24,491.06	$86,630.12	$111,121.18
2,000	$1,618,565.14	$6,990,733.76	$8,609,298.90	$24,523.71	$158,880.31	$183,404.03
4,000	$1,095,875.81	$6,224,377.80	$7,320,253.61	$16,604.18	$141,463.13	$158,067.31

Table 6. Range of Reach Recreation Values for the Base Case Scenario

Percent	Value
5%	$1,979,885.00
25%	$2,551,250.00
50%	$2,939,789.00
75%	$3,388,936.00
95%	$4,079,219.00

Ward presents his results in trips per thousand by county. By keeping this value constant but using 2017 county population as measured by the American Community Survey, we modified the number of trips expected and therefore the number of miles traveled by recreational visitors. We showed an overall increase in miles traveled of about 56 percent based primarily on increased population in Santa Fe, Bernalillo, and Taos Counties between 1982 and 2017. Using Consumer Price Index data, we adjusted the value per mile traveled to 2017 dollars in order to compensate for inflation.

The model uses the daily values assigned by Ward (1987). Fishing and rafting values are separately calculated for the flow on each weekend day over the fishing or rafting season and then combined as reach recreation values. Ward assumes 44 weekend days in the whitewater season (May through September) and 66 weekend days in the fishing season (April through November). We did not attempt to incorporate weekday fishing or rafting values, which biases our results downward. Morrison and Stone (2015a) include an additional day in measuring weekend rafting timeframes, so rafting trips start on Fridays, and we incorporated this modification into the economic model.

Lukens (1986), whose survey work underlies Ward's valuation, interviewed a small number of visitors whose trips to the Rio Chama reach were neither for angling nor for rafting. However, Lukens was unable to extrapolate visitor numbers. He did determine that each visit had an approximate value of $92.90 in 1982 dollars, higher than anglers and lower than rafters. Lukens finds that individuals visiting the river for recreation along the river banks are not responsive to flow changes, as do Daubert and Young (1981). This suggests that the overall economic value of reach recreation is understated because we do not quantify shoreline recreation, but that the change in value we derive as a result of river flow changes is accurate.

5.3. Assumptions and Limitations

This model assumes that the patterns of visitor preference demonstrated by Ward are consistent over the past 30 years. This is a significant assumption, and there is evidence that challenges it. Heinz et al. (2007) demonstrate significant changes in visitor and recreation preferences for a Dutch park and recreational area over periods of less than a decade. Johnston and Rosenberger (2010) observe that values derived from temporal transfers across longer timeframes are not as robust as those performed under shorter timeframes but observe that including updated data regarding consumer recreational preferences can reduce potential time-related error.

Ward (1987) notes that recreational visitors mentioned the Rio Grande in the Taos Gorge as a potential substitute for the Rio Chama. However, there are few other water recreation sites in New Mexico, and the state has become significantly drier since the 1980s (Jones and Gutzler, 2016). It is implausible that new substitutes for rafting and angling have been introduced locally. Insofar as large-scale regional changes have impacted visitor preferences for Rio Chama visitation, the consistency of flows due to San Juan-Chama Project water may have made it more appealing, rather than less. In this case, estimates based on Ward will be downward-biased.

Changes in overall recreational preference may also have occurred. However, Neher and co-authors examine temporal stability of willingness to pay in whitewater rafters in the Grand Canyon (Neher et al. 2017). When they compare the results of a 1985 survey and a 2015 survey, they find no statistically significant difference between willingness to pay for whitewater rafting in 2015 and inflation-adjusted willingness to pay in 1985.

These calculated values also assume that anglers interviewed between May and August are comparable to anglers who fish in April or in the fall months. Because high-value trout fishing on the Rio Chama is primarily an autumn activity, it is probable that the true value of autumn angling is higher than the value calculated here.

6. Reservoir Recreation

The number of weekly visitors at El Vado Reservoir varies seasonally and with reservoir depth. Because greater lake volume results in more shoreline and more lake surface, higher water levels are associated with greater recreational value (see Hanson et al. 2003, Daugherty et al. 2011, and Neher et al. 2013 among others). Ward (1987) finds reservoir recreation value positively correlated with reservoir surface area but does not quantify the value associated with this recreational use.

6.1. Model Framework and Data

The empirical model used to evaluate changes in reservoir recreation is based on Neher et al. (2013), who use linear regression modeling to detect that increased visitation and spending at Lakes Powell and Mead is highly correlated with greater reservoir volume and surface area. In keeping with Neher and co-authors, water elevation is used instead of reservoir area or volume.

Weekly recreational visitation numbers at El Vado Reservoir from July 2007 to June 2018 were provided by New Mexico State Parks (Kolls 2018). Reservoir water elevation is drawn from Reclamation data. Most park visitation takes place in June through September; visitors over the winter are so few that the park closed from mid-December through March from 2011 through 2017. As a result, data for those months do not reflect the true demand for park visitation. Elevation data reveal significant differences in the lake's water levels, with very low lake levels in 2013, and moderately low levels in 2012, 2016, and 2018.

We observed water-flow-related visitation predictors. A plot of visitors to the reservoir mapped out against elevation of the water surface reveals no clear pattern. However, water usage varies over the year. Park visitors during the summer are more likely to participate in swimming and water sports. We can examine how reservoir volume affects each group: November through March, the off-season; and April and May, as well as September and October, the shoulder seasons; and June through August, the summer season. Figure 2 illustrates the patterns observed. Winter (pink) and shoulder season (green) visitors are not responsive to changes in water height. However, summer (blue) visitors increase as water height increases. Variations in average water elevation may result in fixed effects, stripping some of the effect of low water from the regression.

During the summer months, increased reservoir height, and therefore volume, is predictive of more reservoir recreation visits. When interaction variables between season (e.g., summer and shoulder) and water elevation are introduced, the $Elevation * Summer$ interaction term is highly significant with or without fixed effects, although the $Elevation * Shoulder$ interaction term loses its significance when month and year fixed effects are incorporated.

Although water elevation on its own is uncorrelated with visitor behavior, 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. Table 7 and Table 8 show the average visitor count at El Vado Reservoir and Table 9 compares the effect of water levels on the visitor numbers at El Vado Reservoir.

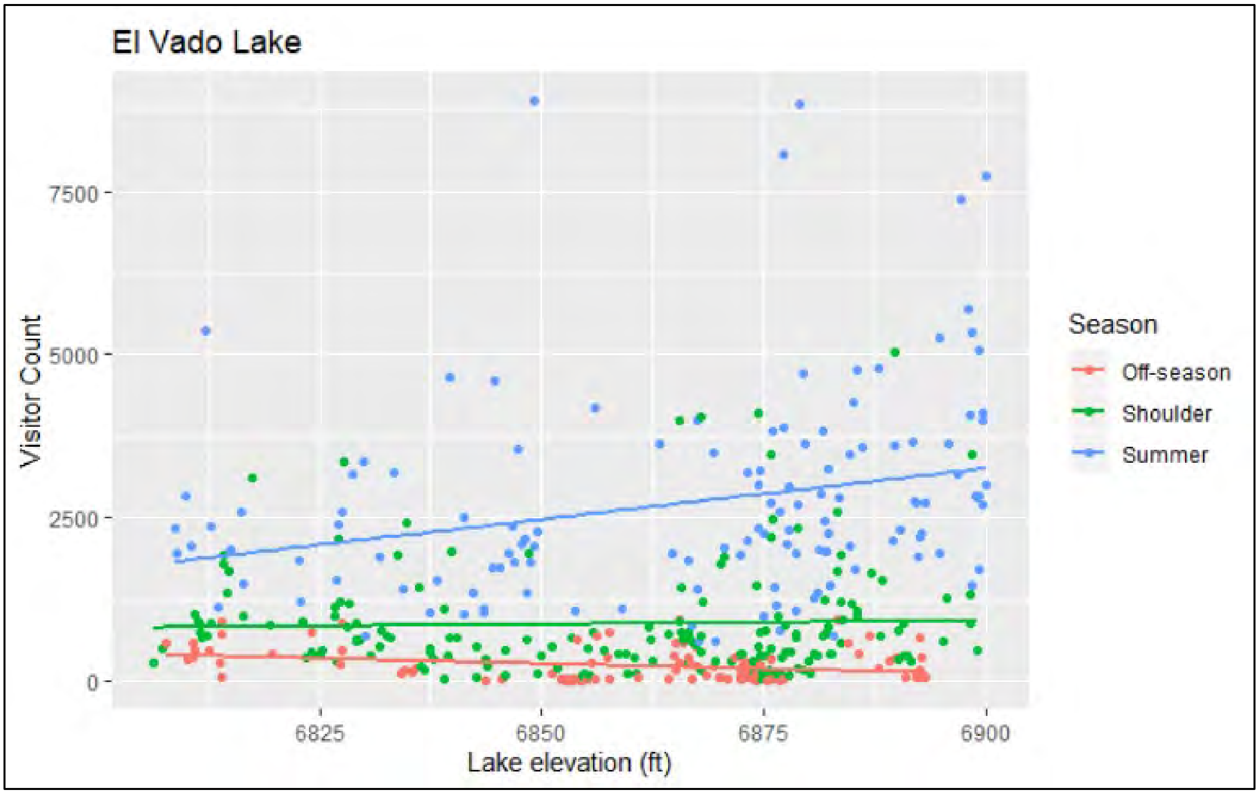

Figure 3. Reservoir visitors by water height.

Table 7. Average Visitor Counts at El Vado Reservoir by Average Month

Month	Obs	Avg	System Dynamics Model	Min	Max
January	18	45	(31)	11	118
February	16	61.6	(40)	10	118
March	19	131.1	(165)	5	663
April	41	331.5	(226)	29	1,241
May	45	911.8	(684)	96	3,470
June	41	2222.4	(1090)	601	5,343
July	44	3514.4	(2060)	1075	8,884
August	45	2421.3	(1079)	690	5,693
September	42	1585.3	(1191)	161	5,033
October	44	648.3	(494)	82	2,174
November	44	414.5	(252)	29	946
December	22	145.3	(163)	6	567

Obs = observed
Avg = average

Table 8. Average Visitor Counts at El Vado Reservoir by Year

Year	Obs	Avg	System Dynamics Model	Min	Max
2007	-	-	-	-	-
2008	25	1993.6	(2068)	53	7,730
2009	52	1281.5	(1693)	6	7,381
2010	52	890.8	(1271)	11	5,343
2011	50	1353.8	(1752)	32	8,839
2012	34	2151.2	(1850)	253	8,884
2013	35	1419.3	(1093)	318	5,377
2014	34	1289.3	(783)	50	3,553
2015	36	1417.5	(1428)	95	8,071
2016	35	834.2	(855)	29	3,980
2017	42	1028.8	(1163)	13	4,752
2018	26	368.4	(517)	5	1,952

Table 9. Effect of Water Levels on Visitor Numbers at El Vado Reservoir

Variables	OLS			
	1	2	3	4
Lake elevation	8.654	5.00	4.689	-5.37
	(2.81)	(2.04)	(4.33)	(5.72)
Elevation * Summer	-	0.364	-	20.06
	-	(0.019)	-	(4.99)
Elevation * Shoulder	-	0.096	-	3.94
	-	(0.018)	-	(4.93)
Fixed Effects				
Month	no	no	yes	yes
Year	no	no	yes	yes

6.2. Value Transfer

We again use Ward (1987) as a source for benefit transfer to determine the dollar value of reservoir recreation enjoyed at El Vado Reservoir. Reservoir recreation includes fishing and powerboating, which are not dissimilar to the fishing and rafting that Ward measures downstream. We therefore analyze three potential valuation rubrics for reservoir recreation, based on the value of reach recreation, discussed above (Table 10). Our lowest value possibility is that reservoir visitors value visiting El Vado Reservoir approximately as much as the lower-value fishing visitors to the Rio Chama reach. The mid-value possibility assigns visitors the same preferences as reach anglers and assumes the same distribution of location as is shown in reach recreation. The highest value possibility assigns reservoir visitors the same preferences as reach rafters.

Table 10. Distribution of Reservoir Recreation Values

	Min	25	50	75	Max
Min	$4,783,242	$5,333,918	$5,455,868	$5,534,824	$5,634,299
Probable	$17,083,960	$19,050,770	$19,486,330	$19,768,330	$20,123,620
Max	$54,724,740	$61,024,980	$62,420,200	$63,323,530	$64,461,620

Ward's travel cost method has two benefits as a source of benefit transfers. The first is that the travel time and expense to El Vado Reservoir are very similar to the travel time and expense to the Rio Chama reach. By using a benefit transfer that appropriately models the site's distance from population centers, we remove a potential source of error. The second is that using Ward's angling and rafting numbers as a baseline permits us to compare reach and reservoir recreation directly. This allows for more transparent modeling and better ability to evaluate trade-offs.

6.3. Assumptions and Limitations

We assume that the pattern of visitors to El Vado Reservoir is similar to the pattern of visitors to the river reach just downstream. This is a significant assumption, since the behavior of individuals whitewater rafting and sport angling may not be generalizable to other outdoor recreation in the same area. Both whitewater rafting and angling are equipment-heavy activities requiring specialized skills, and not all recreational areas are suitable for them. It is plausible that there are more local substitutes for visiting El Vado Reservoir (e.g., visiting a park or another lake), reducing the average travel distance of visitors.

The difficulty in evaluating this benefit transfer results in a wide margin of error, in which the average value for yearly reservoir recreation visits is calculated between $5.46 million and $62 million. This limits the conclusions we can draw. However, this valuation is adequate to see trade-offs between reservoir and river recreation scenarios.

7. Ecosystem Services Valuation

Properly functioning ecosystems provide goods and services that are important to human wellbeing (Brown et al. 2007). We base our distinction between goods and services on the framework described by Brown and co-authors. An ecosystem good is a product of the natural system. In New Mexico, commonly harvested ecosystem goods include game, fish, firewood, and piñon nuts. The category of ecosystem goods also includes intangibles such as recreational opportunities or aesthetic enjoyment. An ecosystem service is a system process outcome that has value to humans. This includes such functions as clean air produced by forests, flood control contributed by wetlands, purified water resulting from aquifer recharge, or pollination provided by bees.

In our model, we use the term *ecosystem services value* to describe the non-use benefits provided by the natural system in the Rio Chama canyon, and we account separately for ecosystem benefits that are experienced (e.g., visits) or consumed (e.g., fish that have been caught).

The complexity of ecosystems makes it difficult to arrive at an absolute value for their services. Because the purpose of this model is to examine flow-driven trade-offs between value drivers in the Rio Chama system, we focus on ecosystem services plausibly impacted by streamflow changes. We are limited by the scarcity of data about quantifiable ecosystem impacts that can be associated with flow pattern changes.

It is likely that we do not know all of the ways in which the Rio Chama system contributes to larger ecosystem benefits, and that the overall ecosystem services value that we calculate is substantially lower than the real value. This subject is ripe for further research efforts, both to identify additional ecosystem impacts resulting from streamflow changes and to quantify their economic value.

7.1. Ecosystem Services Literature

To assign a value to ecosystem services, it is first necessary to define them. Brown et al. (2007) describe the theory underlying ecosystem services valuation. Ecosystems can be described as natural capital, producing goods or benefits that are incorporated into human production and result in some level of utility or value for consumers. This conceptualization of ecosystem services deliberately limits ecosystem service valuation to a system's impact on human wellbeing. It explicitly excludes metaphysical or philosophical questions about the intrinsic value of the natural world, and it draws a distinction between the economic value of the system (which is rooted in human preferences) and the ecological uses of the system (which are connected to its physical and biological characteristics). These two methods of ecosystem evaluation may be in conflict; for example, habitat that supports an undesirable species may have real ecological use but negative economic value.

Strictly utilitarian ecosystem service valuation is challenged by Retallack and Schott (2014), among others. They argue that incorporating ecological value dimensions is necessary to account for irreversibility and uncertainty, particularly when approaching a critical ecological threshold. Perrings (1995) shares this view. He further argues that ecological uses in a system may have unrecognized economic value, making true ecosystem services valuation impossible. The inability to know all the possible consequences of ecological change is an unavoidable limitation in ecosystem services valuation.

Boyd and Banzhaf (2007) clarify that ecosystem service values comprise the final outcomes that contribute to human wellbeing. For example, the value of clean water for municipal use is included in ecosystem service value, while clean water to support trout populations is not because it is an intermediate product, and its value is captured by the ecosystem value provided by the trout population.

Despite this formalized definition, ecosystem services are hard to define in objective terms (Boyd and Banzhaf 2007). This is due in part to a dearth of price information, since no market exists for them, but it is also due to lack of precision in defining the service to be valued. Context matters: a stretch of river with a year-round 500 cfs flow supports a completely different ecosystem in the arid West than it does in the Southeast. Values depend on location and time. The magnitude of a change is also important. Ecosystem services valuation is more accurate when examining small changes that have identifiable substitutes (Brown et al. 2007). Large or irreversible changes are difficult to value (Laskett 1995).

The literature examining riverine ecosystem services values focuses primarily on the restoration of degraded river habitat (Gopal 2016). While the Rio Chama below El Vado Dam has not necessarily degraded habitat, it has been dramatically altered by human engineering (Morrison and Stone 2015b). In addition to the impacts of reservoirs and dams, the river's total discharge has been increased by approximately 25 percent due to the imported water from Reclamation's San Juan-Chama Project. As Jager and Smith (2008) observe, research examining hydrological impacts of dams tends to assume that the best ecological outcomes are produced by natural flow regimes and that deviations from natural flows are ecologically damaging, but this study provides little evidence to support this assumption.

The permanent human modifications to the Rio Chama system make a return to historical flows nearly impossible, so further information about the Rio Chama's ecosystem is necessary to determine what the best ecological outcome might be. Gopal (2016) suggests that the correct benchmark is an environmental flow, defined as flows sufficient to sustain a given freshwater ecosystem and the human activities reliant on it. Correctly defining such a flow regime for the Rio Chama would involve significant resource investment and may be a productive topic for further study. Without a clearly delineated best environmental flow outcome, however, we rely on ecosystem outcomes that can be related to streamflow patterns to act as proxies for the system as a whole.

7.2. Model Framework

The benefit transfer used in this model is a single-study unit value transfer based on Weber and Stewart's (2009) valuation of Rio Grande restoration efforts. The source survey takes place in the same river basin and state as Rio Chama, and the Rio Chama is a Rio Grande tributary. This study captures flow-related changes in several dimensions of ecosystem services and decomposes the overall value to show what portion is associated with what change. It uses both CVM and a choice experiment (CE), to calculate willingness-to-pay. CE asks respondents to choose between a menu of attributes (with a cost) while CV asks if they would be willing to pay $x.

The Weber and Stewart survey focuses on restoring a 17-mile stretch of the Rio Grande in a relatively urban area. The outcomes of the source survey show that a significant portion of individual willingness to pay for riparian restoration is tied to the restoration of native trees, particularly cottonwood. Morrison's 2015 modeling of the Rio Chama includes cottonwood recruitment modeling. We use cottonwood recruitment success as a proxy for ecosystem services valued by New Mexicans.

The accuracy of this modeling strategy is limited. Successful cottonwood growth requires specific streamflows in the spring months. Appropriate streamflow for cottonwood recruitment may or may not correlate with optimal or appropriate streamflow for other native species.

Weber and Stewart's survey discusses two birds (the bald eagle and the endangered Southwestern willow flycatcher) as well as an endangered fish (the Rio Grande silvery minnow). The Rio Chama is a habitat for many bird species, as well as brown trout. Weber and Stewart's study area, the urban portion of the Rio Grande, is of significant historical importance and provides recreational benefits to locals that may be incorporated into their valuation. The Rio Chama is similarly important to locals, both as a recreational area and as a support for the rural agricultural communities in the area.

The source survey was conducted by mail and sent to residents of Albuquerque. The potential benefits offered to survey-takers included a 10 percent increase in fish and wildlife population, thinning of dense vegetation, dominance of native tree types, and additional overbank flooding and other natural processes expected to support the riverine ecosystem. The mean values associated with each benefit are listed in Table 11. The 95 percent confidence interval for increased wildland species population and overbank flooding results in negative values at 95% confidence.

Table 11. Weber and Stewart (2008) Rio Grande Restoration Values

Proposed Change	Mean	95% Confidence Interval
10% increase in wildland species population	$7.34	-$12.89 to $25.05
Moderate tree thinning	$40.49	$22.57 to $62.82
Complete tree thinning	$35.08	$16.29 to $58.75
At least half of trees are native species	$33.81	$15.11 to $56.81
Native tree dominance	$59.03	$40.97 to $83.03
Overbank flooding and other natural processes	$15.11	-$4.17 to $31.56
Full restoration by CE	$156.60	$127.21 to $203.17
Full restoration by CVM	$46.80	$6.33 to $110.70

We apply the decomposed values for restoration to the Rio Chama study site. Streamflow changes are unlikely to impact species population or tree thinning. Native tree dominance and overbank flooding can be captured by riparian cottonwood recruitment, as modeled by Morrison and Stone (2015b). We incorporate only the native tree dominance and the overbank flooding dollar values in our calculations, and we adjust the dollar value from 2006 to 2017 dollars to reflect inflation.

Johnston and Rosenberger (2010) note that spatial variation between sites can be a significant source of error. The population assumed to care about the given study area may vary. Weber and Stewart assume that the Middle Rio Grande Bosque is valued by Albuquerque residents, who can use the Bosque for recreation. We assume that Rio Arriba County residents value the ecosystem of the Rio Chama area. There are no standard spatial pattern adjustment mechanisms in the benefit transfer literature (Johnston and Rosenberger 2010), so this adjustment is an ad-hoc assumption based on the distance coefficient calculated in the source study. Weber and Stewart find that distance from the Rio Grande has little impact on an individual's ecosystem value. Although it is likely that people throughout New Mexico have a positive ecosystem services value on the Rio Chama, due to its importance as a tributary of the Rio Grande and its unusual beauty, we assume that only residents of Rio Arriba County have an ecosystem services interest in the study area. This is likely to bias our numbers downward.

Albuquerque respondents were more wealthy and better educated than average residents. Higher income predicts a higher willingness-to-pay for river restoration. Median income in Rio Arriba County is only 63.2 percent of average income in Albuquerque. We reduce willingness-to-pay proportionate to the difference in average income. It is probable that lower-income households have a level of disposable income that is disproportionately smaller to their overall income, and therefore a linear transformation of willingness to pay may overstate the real valuation.

In Weber and Stewart's results, individuals born in New Mexico have greater willingness-to-pay than individuals not born in New Mexico. Although 78.5 percent of people in Rio Arriba were born in New Mexico, compared to 46.7 percent in Albuquerque, we do not correct for this difference. Since birth in New Mexico has a six-times greater upward effect on willingness to pay than income, the bias in the ecosystem valuation numbers from this factor is likely to be downward.

River restoration literature uses a value-per-mile estimate, so we multiply the transformed Weber and Stewart value by two to obtain our base estimate for river restoration per household, since the source study examines a 17-mile stretch of river and the area of interest on the Rio Chama is 34 miles.

We assume that riparian recruitment success is binary, and we assign the full value when there is a 95 percent likelihood of successful recruitment in a given year. In other years, the value is zero. The baseline values associated with ecosystem services, under different likelihoods of successful recruitment, are provided in Table 12.

Table 12. Base Case Ecosystem Services Values – Value of Reach Recreation

	Baseline Assumption	Conservative Assumption
5%	$0	$0
25%	$67,306.00	$11,374.00
50%	$95,215.00	$16,091.34
75%	$200,724.00	$33,922.36
95%	$311,975.00	$52,723.78

The survey response rate for Weber and Stewart was very low, at 16.9 percent. We calculate the baseline value for ecosystem services assuming that survey respondents accurately reflect the willingness-to-pay of all households. We also calculate the baseline value under the assumption that the non-respondents had a zero value for river restoration, and only 16.9 percent of households are willing to pay.

7.3. Other Comparable Valuation

Greenley et al. (1981) use CVM to determine the willingness of residents of Fort Collins and Denver, Colorado, to pay to avoid mining pollution in the South Platte River. They calculate a value of $23 annually per household (in 1981 dollars) to keep the river in its current condition. This study does not look at changing values associated with changes in streamflow.

Berrens et al. (1996) examine the ecosystem service value of maintaining instream flows to the Rio Grande above Elephant Butte to support the endangered Rio Grande silvery minnow. Using a CVM survey, they find a mean annual household willingness to pay of $28.73 for instream flows (in 1986 dollars) through 170 miles of river to sustain the silvery minnow population. Flow rates were not examined.

Loomis et al. (2000) examine household willingness to pay to restore the South Platte River, near Denver, Colorado. They find a median household willingness to pay at around $21 per month (in 2000 dollars) to restore habitat for a 45-mile stretch of river. River restoration would improve habitat for native species, increase survival of native fish, reduce pollution from ammonia and nitrates, and improve the river's water-filtering qualities. The South Platte is more urban and has much more agricultural diversion than the Rio Chama, so this comparison is of limited use.

7.4. Assumptions and Limitations

While some argue against environmental valuation on the basis that the environment has an absolute right to be protected, environmental economists note that this right does not appear to be widely recognized in practice (Hanley 1995). In many cases, failure to include environmental effects into cost-benefit analyses leads to other values being prioritized over ecosystem concerns, particularly when the costs or benefits associated with those values accrue to a concentrated group with political influence (Loomis 2000). It is true that including environmental values in an analysis does not necessarily ensure a good outcome; the complexity of this task can result in poor value estimation and consequent inefficiencies in resource use (Holdgate 1995). In most cases, however, even imprecise value estimations are more accurate than the zero value implied by omitting environmental values from the analysis process.

The ecosystem services values derived from this model are the least precise of the estimates we make. This is due in part to the greater difficulty associated with estimating non-use environmental values. Kaul et al. (2013) find that changes in environmental quality are particularly difficult to quantify using benefit transfer and are associated with higher error rates than other types of benefit transfers. Heinz and co-authors (2016) warn that the temporal dynamics of ecosystem management can change ecosystem values profoundly over less than a decade. This should be noted as a model limitation, since ecosystem services values in this analysis are calculated over a 1-year period. The potential for warming or aridification due to climate change is likewise not incorporated into the model (Pace et al. 2015). There is little empirical support for a general assumption that preferences remain stable over long periods (Frederick et al. 2002 and Richardson et al. 2015). Laskett (1995) notes that scarcity value may drive rapid increases in social preference for natural systems that are in danger of degradation. 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.

Richardson et al. (2015) suggest that spatial scaling is another source of error in ecosystem services benefit transfers. The value of a 1-acre ecosystem cannot be multiplied by 10 to determine the value of a 10-acre ecosystem. This casts doubt on the process of using a per-mile value for the Rio Grande and transforming it to an equivalent per-mile value for the Rio Chama. The spatial scale is not wildly unequal, however, with a 17-mile stretch of the Rio Grande compared with a 34-mile stretch of the Rio Chama. A more conservative estimate would consider the stretch of the Rio Grande examined by Weber and Stewart (2009) equivalent to the stretch of the Rio Chama examined in this study. Such an assumption would reduce ecosystem services values by one-half. Spash and Vatn (2006) go further, suggesting that the accuracy of spatial transfer for ecosystem valuation is so low that it should be used only as a guideline.

7.5. Unique Cultural and Ecosystem Values

The Wild and Scenic River designation is a potential indicator of additional values associated with the Rio Chama but is not captured in the benefit transfer process. As research into the economic implications of the Wild and Scenic River designation is limited, its effect could not be captured within the model, but it should be considered as a potential multiplier of ecosystem services values. Malm (2012) examines economic growth effects from this designation and concludes that it is associated with statistically significant lower economic growth. Moore and Siderelis (2002) focus on economic benefits from recreation. Smith and Moore (2011) examine the benefits accruing to communities from proximity to two Wild and Scenic Rivers, determining that river users valued the preservation of open spaces, the aesthetic beauty of the area, the existence of fish and wildlife habitat, and the contribution of the area to community pride in addition to tangible economic or recreational benefits. The literature does not attempt to calculate the ecosystem values represented by the Wild and Scenic River designation.

The cultural importance of the Rio Chama within the Rio Chama basin is discussed in Gonzales et al. (2013). The authors note the difficulty of using dynamic modeling techniques to adequately model socio-cultural impacts associated with the river, particularly the historical importance of the agricultural and irrigation community. The oldest of New Mexico's acequias was constructed on the Rio Chama in 1598, and the river supports 30,000 acres of farmland for economically precarious communities, about 10,000 acres of which are upstream of El Vado Reservoir. While the portion of the Rio Chama that is currently used for irrigation downstream of El Vado Reservoir has minimal diversions above Abiquiu Reservoir, the value of ecosystem services provided by the upstream river reach may be enhanced by its historic role as the origin of community wealth and wellbeing. The difficulty of evaluating this critical social role of rivers is also noted in Jorda-Capdevila and Rodríguez-Labajos (2017). 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.

8. Indirect Impacts on the Local Economy

Entry fees comprise only a small part of the economic impact of Rio Chama recreation. Local spending on gasoline, food, retail goods, lodging, guides, and rentals dwarf the impact of the $5 entry fee to El Vado State Park or the $10 reservation fee for rafting the Rio Chama reach.

Rio Arriba County is the beneficiary of indirect economic impacts from tourism. This rural county in northern New Mexico covers 5,858 square miles and has a population of 40,040. Major employers include local and state government, government contractors, ranching and farming, and limited-service restaurants and retail establishments (IMPLAN Group 2018).

8.1. Indirect Valuation Literature

McKean et al. (2005) use IMPLAN valuation software to evaluate the economic effect of rafting on the Salmon River in central Idaho. They find average spending of $1,394 per trip in 1998 dollars, of which about 45 percent is entertainment services, primarily guide services. Other significant expenses include bus or tour boat, 15.3 percent; restaurant, 8.9 percent; lodging, 13.3 percent; and air travel, 6.6 percent.

Hjerpe and Kim (2007) evaluate economic effects of rafting on rural communities surrounding the Grand Canyon. They also use IMPLAN as a primary evaluation tool. They find an average trip expenditure of approximately $1,001 in 2007 dollars for rafters working with commercial rafting companies and $680 for non-commercial expeditions. Sector spending is similar between the two groups, and we base our sector approximation on their results.

Our primary adjustments are to make fuel costs and entry fees explicit, since we have basic data on these expenses. We base costs on a 2016 average fuel economy of 17.9 mpg and an average fuel price from 2016 through 2018 of $2.65 per gallon in 2017 dollars, resulting in $0.148 spent on gasoline per mile traveled (Sivak and Schoettle 2017 and U.S. Department of Energy 2019). We assume a
$5 entry fee for reservoir visits and a $20 fee for rafting ($10 for a reservation through BLM and a $10 use fee for the launching area at Cooper's El Vado Ranch). We assume about 14 percent of rafting dollars are expended on commercial rafting, based on a 1:2 ratio of commercial to non-commercial rafting trips and using Hjerpe and Kim's commercial expedition cost percentage.

Because these numbers are used as inputs in IMPLAN's proprietary modeling system, we opt for simple rather than complex transformations and present conservative and moderate scenarios. While we incorporate known values where possible, much of the sector assignment of tourist spending is extrapolated from surveys taken in other states and focusing on whitewater rafting expenditures. These numbers should be used with caution, since no data specific to the Rio Chama area have been collected.

8.2. IMPLAN Modeling

We use IMPLAN to perform an analysis of indirect impacts from Rio Chama recreation (IMPLAN Group 2018). Our primary focus is the indirect impact of tourist dollars coming into Rio Arriba County, so we exclude visits from individuals who live in Rio Arriba County. Because values assigned to reach and reservoir recreation are based in travel cost methodology, we assume that they represent actual costs incurred by the visitor. However, we remove the value of travel time, which does not have a local economic impact.

Hjerpe and Kim (2007) discuss leakage, or the problem of recreational spending taking place outside of the local area, particularly in rural locations in which specialized equipment may not be readily available. This is likely to be an issue in Rio Arriba County, which has few large retail stores. Its largest city, Española, has a Wal-Mart but no specialty outdoor outfitter. Commercial rafting trips may be organized by outfitters based in Santa Fe, Taos, or Pagosa Springs, Colorado. Hjerpe and Kim find a capture rate, or expenditure less leakage, of 43 percent for whitewater rafting in rural northern Arizona. We use this capture rate to estimate tourism expenditures in Rio Arriba County (Table 13).

Table 13. Break-down of Average Trip Costs in 2017 dollars (IMPLAN)

	Fishing and Reservoir Trips	Rafting
Average expenditure per trip	$269.54	$942.88
Limited-service restaurants	$43.80	$153.22
Full-service restaurants	$43.80	$153.22
Recreational equipment	$67.79	$237.13
Park fees	$5.00	$20.00
Retail - gasoline stores	$22.73	$22.20
Hotels and motels	$14.66	$51.29
Transportation	$21.29	$74.49
Amusement and recreational services	$0	$130.12
Retail - misc. stores retailers	$50.46	$101.21

8.3. Assumptions and Limitations

IMPLAN's input-output model includes a number of simplifying assumptions in order to develop the required relationships. All of these assumptions are maintained. In addition, we base industry category spending on reported outcomes for similar studies (Hjerpe and Kim 2007 and Guo et al. 2017). Actual spending patterns in northern New Mexico may vary from observed spending patterns at other locations. The literature primarily discusses whitewater rafting at prominent destinations, which may result in overestimation of tourist spending, given the relative obscurity of Rio Chama rafting. For example, Hjerpe and Kim analyze rafting down the Grand Canyon, which had about 21,000 rafters in the 2001 season they examine, compared to the 2,000 rafters allowed permits for the Rio Chama (2007).

9. Indirect Environmental Impact of Hydroelectricity

The electricity sector accounts for 28.4 percent of U.S. greenhouse gas production, outstripped only by transportation, which accounts for 28.5 percent. Hydroelectricity is a significant source of non-greenhouse-gas-emissions-producing electricity generation in the United States. In this context, U.S. greenhouse gas emissions are affected directly by river and reservoir management. As dam releases are managed to maximize power generation, the power produced directly substitutes for other power sources. However, the impact of this substitution depends on the type of generation being replaced by hydropower generation.

9.1. Energy Markets and Greenhouse Gas Emissions

U.S. electricity generation has daily and seasonal patterns of high and low demand, which means that many generators do not run during low-demand times. In theory, electricity is first sourced from the lowest-variable-cost generators, usually wind, solar, hydroelectric, and nuclear. Because these four types of generation pay little to nothing for their fuel, they can run at low cost. When demand for electricity exceeds this supply, fossil fuel generation is brought online. The order in which it is used depends on fuel costs.

However, the specific technical characteristics of generators changes their use in practice. Some types of generation require long start-up or ramping periods before they can produce electricity. Both coal and nuclear plants are in this category. U.S. nuclear plants run constantly unless they are out of service for maintenance. Ramping production up or down usually takes several days, so they remain in service except during maintenance and refueling periods (Davis and Wolfram 2012). On average, U.S. reactors remain in service around 94 percent of the time (U.S. Department of Energy 2019). Zero-carbon energy sources such as wind power or solar power are passively fueled, and their output is not fully predictable (Henriot and Glachant 2013). They are considered non-dispatchable resources—grid operators are not able to scale them up or down depending on demand. They are available only when the sun is shining or the wind is blowing; therefore, they must be balanced by generation that is available at night or when the air is calm. As a result, more responsive natural gas plants are frequently dispatched to provide power, despite having higher marginal costs of production.

9.2. Indirect Effect on Intermittent Renewable Energy Production

Intermittent generation also introduces more variability to the grid. Day-ahead forecasts for wind generation can be off by up to 20 percent, a level of variation that is far greater than the expected variation due to changing load demands. Intermittent renewables have not traditionally had the capacity to provide operating reserves or other ancillary services, although this is not an insurmountable technical barrier (Henriot and Glachant 2013 and Hansen et al. 2016).

Solar energy production has an upper bound defined by the rising and setting sun, although atmospheric conditions can reduce the power produced. Because of the unpredictable variation in solar production and the significant amount of solar energy produced by consumers, it is common to subtract solar energy production from overall energy demand, treating it as negative load rather than positive generation (Henriot and Glachant 2013). In a grid with high solar generation, the end of the solar production day comes at the same time that customers turn on their lights. As a result, net load (load less solar production) shoots up in a short period, requiring multiple generators to come online and start producing power. The type of generation equipped to respond quickly to changing conditions is referred to as flexible generation, and it is a critical component to incorporating more renewable energy on the U.S. grid.

9.3. Research and Literature

Henriot and Glachant (2013) discuss the dynamics of intermittent renewable integration into the European grid and the problem that current economic incentives do not adequately reward power sources flexibility. The authors analyze a significant body of literature discussing the importance of increasing flexible generation responsive to solar load as a prerequisite for reaching greater grid penetration for renewable generation. Although this article focuses on European markets, the authors' criticisms apply to the U.S. power structure, as well.

Investment driven by real-time electricity price signals is inadequate, since power markets are structured to pay marginal costs to the marginal generator, and intermittent renewable generation is modeled as inelastic negative load rather than positive generation. The authors argue that this structure serves to isolate intermittent renewables from the market, leaving them reliant on government subsidies rather than able to stand on their own merits as low-marginal-cost generation. They argue that changing price or non-price compensation on the larger market to reward flexible generation would make intermittent renewable generation more viable without subsidy. Changing dam dispatch is an alternative way to increase flexible generation, and this paper argues that flexible generation impacts big-picture solar viability.

Non-market values associated with maintaining the riverine ecosystem and non-market values associated with improving overall air quality and decreasing greenhouse gases are in conflict, since changing river flows to benefit one dimension of value would negatively impact the other. These two non-market values have been studied separately, but there is little research looking at the ways in which they interact and public preferences between them.

The economic impact of changing hydropower flows in order to improve ecosystems is addressed by Harpman (1999), who examines the dollar value lost due to reduced peak-hour generation at Glen Canyon Dam. Harpman finds an 8.8 percent decrease in revenues when dam operation changes to reduce negative impact on the riverine ecosystem. However, this finding predates the expansion of solar and wind generation that drives potential indirect ecological benefits accruing from using hydroelectricity as a flexible backstop for intermittent renewables.

Jones et al. (2018) also examine the relationships between riverine ecosystems and greenhouse gas emission reduction. This paper discusses the outcome of a national contingent valuation survey with around 4,000 participants. It examines non-market values related to Glen Canyon Dam hydroelectric flow patterns. This survey discovers that when riverine environment is the only non-market-value dimension presented, survey-takers prefer flow regimes that prioritize riverine ecosystem needs. However, when the impact of peak power generation on greenhouse gas emissions and renewable energy integration is included in the value decision, survey-takers prefer to maintain a flow pattern that prioritizes clean energy production. This suggests that including peak power impacts on the ecosystem is important when valuing dam flow patterns.

9.4. Valuation and Limitations

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. This is an area that should be considered for primary research.

10. Scenario Analysis

We compare the economic effects 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.

10.1. Matching Reservoir Evaporation

This scenario incorporates San Juan-Chama Project outflows from Willow Creek that have been shifted to balance evaporation at Abiquiu and Heron Reservoirs. After modeling the adjustments that can be made within our existing model, it became clear that this shifting of flows had no effect on yearly outcomes, since all San Juan-Chama water must move through the system over the course of the year. Ultimately, changing storage location had no effect on the economic outcomes in the through-area. It seems probable that there are economic differences associated with shifting recreational use from Abiquiu to Heron or Heron to Abiquiu, but we cannot capture these within the limits of our model without modeling economic effects of recreational visits at Abiquiu Reservoir.

In this scenario, we do not rely on Monte Carlo modeling. Instead, we model the economic effect of 10 years of historical streamflow data (2008 to 2017) and compare those outcomes to the evaporation-consistent counterfactual. Note that yearly average values for this deterministic scenario cannot be directly compared to the Monte Carlo values obtained in the baseline modeling, since the past 10 years of streamflow and water storage have been substantially below the historical data (1975 to 2007) used to calibrate the stochastic model (Table 14).

Ecosystem services are decreased, since the deterministic streamflows used by the model do not provide flooding or cottonwood recruitment events. This appears to be an artifact of the modeling process rather than a genuine trade-off between ecosystem services and Heron Reservoir management decisions.

Table 14. Evaporation Scenario

	Historical		Evaporation-balanced	
	10-year	Yearly	10-year	Yearly
Hydro revenues	$8,404,160	$840,416	$8,404,160	$840,416
Hourly submodel	$8,826,907	$882,691	$8,826,901	$882,691
Reach recreation	$38,614,930	$3,861,493	$38,614,930	$3,861,493
Reservoir recreation	$146,221,600	$14,622,160	$146,221,600	$14,622,160
Ecosystem services	$0	$0	$0	$0
Indirect	$17,165,510	$1,716,551	$17,165,510	$1,716,551
Total	$210,406,200	$21,040,620	$210,406,200	$21,040,620

10.2. Changing the Dock at Heron Reservoir

Heron Reservoir is less than 5 miles upstream from El Vado Reservoir and primarily holds San Juan-Chama water. It has more than twice El Vado's average annual visitors. Because of its status as a no-wake body of water, a marina and sailing club are based there. However, the dock is unusable when water levels are low. Water access, particularly boat dock access, may have significant effects on recreation accessibility and economic value (Daugherty et al. 2011). In the baseline scenario, we do not find that boat dock levels affect recreational use at El Vado Reservoir. In this scenario, we evaluate the effects to El Vado Reservoir if Heron Reservoir water storage rules were changed and the Heron Reservoir dock were moved to increase access at lower lake levels.

The past 10 years of water releases from Heron Reservoir are modeled under three scenarios: a high-water scenario, a historical scenario, and a low-water scenario. We examine the effects of the scenarios on individual dimensions of value as well as overall system value. Instead of the stochastic modeling performed in other analyses, we use a deterministic model based on output from the USACE's Upper Rio Grande Water Operations Model over a 10-year time frame. We present the cumulative 10-year values and the average yearly value. We report the probable reservoir recreation values for El Vado Reservoir and Heron Reservoir separately.

Weekly Heron Reservoir visitation data from 2008 through 2017 were supplied by New Mexico State Parks and were used to analyze the effect of changing reservoir height, as explained in Section 6. *Reservoir Recreation*. We use a similar empirical model to evaluate the relationship between reservoir height, visitor numbers, and boat dock accessibility. Heron Reservoir recreational visitor values are added to the base model.

Heron Reservoir's visitor model is substantially consistent with the model used for El Vado Reservoir. In June through August, a 1-foot increase in lake depth corresponds with an additional 41 weekly visitors, about twice the effect shown at El Vado Reservoir. Unlike El Vado visitors, Heron Reservoir visitor numbers are modestly responsive to changes in reservoir height during the shoulder months (April, May, September, and October) (Table 15 and Table 16). We incorporate year and month fixed effects and find that month fixed effects are consistently significant, while year fixed effects are not. Since Heron Reservoir's yearly water supply is less responsive to weather and snowpack, this is unsurprising.

No relationship is found between visitor numbers and dock accessibility (Figure 4). This is a surprising result, since both the literature on reservoir access and public comments by Heron Reservoir users suggest that dock access drives visitation.

Because dock accessibility has no effect on the number of recreational visitors to the lake, we see no change in outcome with a lower dock location. Given the data available, no increased economic value is associated with the lower dock.

Table 15. Heron Reservoir Visitation Regression Analysis

Variables	OLS			
	1	2	3	4
Lake elevation	72.77***	21.04**	8.785	1.082
	(9.085)	(6.63)	(9.204)	(9.048)
Elevation x Summer	-	0.6463***	-	40.837***
	-	(0.02718)	-	(6.435)
Elevation x Shoulder	-	0.1949***	-	11.001*
	-	(0.02380)	-	(5.784)
Boat dock access	-1751***	71.22	272.809	275.828
	(452.0)	(320.8)	(368.572)	(355.08)
Fixed Effects				
Month	no	no	yes	yes
Year	no	no	yes	yes

90% significant, * 95% significant

Table 16. Deterministic Model Runs Targeting Heron Reservoir Levels

	Historical		Low Water		High Water	
	10-year	**Yearly**	**10-year**	**Yearly**	**10-year**	**Yearly**
Hydro revenues	$8,954,870	$895,487	$11,615,500	$1,161,550	$6,877,632	$687,763
Hourly submodel	$9,421,761	$942,176	$12,242,470	$1,224,247	$7,231,969	$723,197
Reach recreation	$38,614,930	$3,861,493	$38,614,930	$3,861,493	$38,614,930	$3,861,493
Reservoir recreation	$154,461,900	$15,446,190	$195,541,500	$19,554,150	$137,023,500	$13,702,350
Ecosystem services	$0	$0	$0	$0	$0	$0
Indirect	$17,934,750	$1,793,475	$21,769,650	$2,176,965	$16,306,840	$1,630,684
Subtotal	$219,966,450	$21,996,645	$267,541,580	$26,754,158	$198,822,902	$19,882,290
Heron direct (probable)	$399,631,005	$39,963,101	$58,313,303	$5,831,330	$476,661,282	$47,666,128
Heron indirect	$98,868,711	$9,886,871	$14,426,711	$1,442,671	$117,926,001	$11,792,600
Total	$718,466,166	$71,846,617	$340,281,594	$34,028,159	$793,410,186	$79,341,019

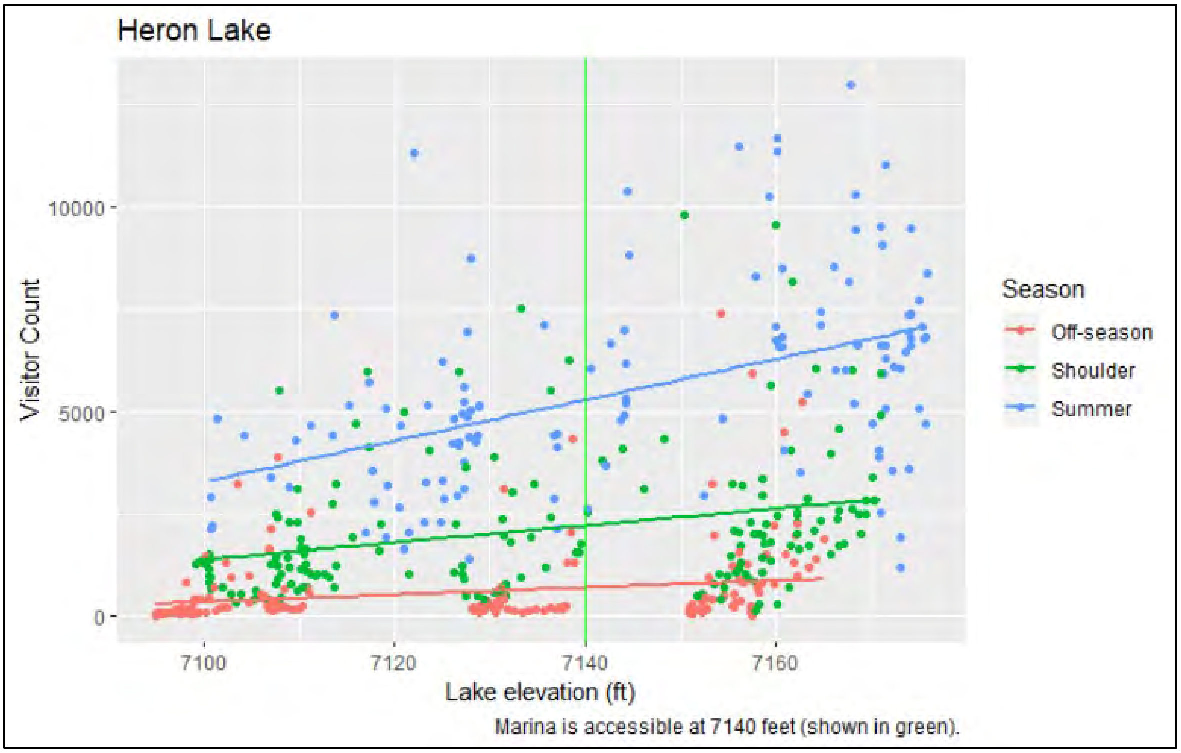

Figure 4. Heron Reservoir visitation patterns.

Our calculated 10-year value for Heron Reservoir visitors under the historic flow scenario is $1,301,052, within 10 percent of actual 10-year visitor numbers of $1,205,362. The high-water scenario predicts approximately $1,551,834 visitors over the same period. 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.

The low-water scenario reveals the limitations of this analysis, however —the minimum Heron Reservoir level used is 7005 feet, compared to a minimum low level in the past 10 years of 7095 feet. When the linear regression used to calculate visitor patterns is extended to these low levels, the model returns negative visits. We truncate visitor numbers at zero and find a predicted visitor number of 189,847 over a 10-year period. However, it is clear that we cannot accurately extrapolate from current visitation patterns when lake levels drop dramatically. Consequently, we recommend that no conclusions be drawn from low-water scenario outcomes.

Better data about visitors at Heron and El Vado Reservoirs would improve our understanding of visitor and spending patterns and their relationship with reservoir height. Visitors may increase time or money spent in the area when preferred recreational activities such as sailing are available, or better reservoir conditions may attract visitors from farther away. Further research in this area might also lead to more accurate ways to predict visitor patterns in very low water conditions.

10.3. Weekend Versus Constant Flow

In this scenario, we examine the effect of further managing summer weekend streamflows to ensure that they always exceed 600 cfs, the minimum cutoff for downstream rafting. We compare the outcomes to the baseline scenario and to a scenario in which streamflow remains at no less than 400 cfs for all summer days.

The 600 cfs weekend scenario balances higher weekend flows with lower weekday flows and results in the same overall yearly streamflow as the baseline scenario. The constant 400 cfs scenario does not have a mechanism to make up for excess summer flow at other times of year, and so the scenario ends with less water stored.

We find that enhanced weekend flows increase the system's value by 3.3 percent. Increased weekend flows improve all dimensions of value except for reach recreation, which decreases by less than 1 percent. Unsurprisingly, its biggest effect is a 28 percent increase in reach recreation value. Hydroelectric revenue increases by approximately 10 percent. Maintaining a constant 400 cfs flow throughout the summer increases hydroelectric values by about 18 percent and reach recreation values by about 8 percent, while decreasing reservoir recreation and indirect tourist revenue for an overall economic effect of a less than 1 percent value decrease (Table 17).

These outcomes are unsurprising, as increased streamflow benefits downstream recreation while slightly decreasing the attractiveness of reservoir recreation. Higher streamflow in the summer increases the value of hydroelectricity generated because of high electricity prices. Indirect effects of tourism follow the increase in downstream recreation, and the ecosystem services values we model are not significantly affected by higher summer streamflows.

Table 17. Comparing Alternative Summer Flows

	Baseline	600 cfs weekend summer	Constant 400 cfs summer
Hydro revenues	$1,012,011	$1,116,068	$1,194,381
Hourly submodel	$1,051,743	$1,151,499	$1,248,631
Reach recreation	$3,650,262	$4,682,899	$3,944,460
Reservoir recreation	$19,486,330	$19,174,840	$18,849,660
Ecosystem services	$47,791	$47,791	$47,811
Indirect	$2,138,315	$2,204,640	$2,116,706
Total	$26,334,709	$27,226,238	$26,153,018

10.4. Blue Ribbon Tailwater Fishery

The final Rio Chama scenario is one in which the annual hydrograph and the water quality (especially turbidity) of the water released from Abiquiu Reservoir support the presence of a Blue Ribbon tailwater fishery downstream from El Vado Dam. Data related both to flow effects and to economic outcomes are too sparse to perform the hydro-economic modeling used elsewhere in this report. Instead, we discuss the literature related to tailwater fishery development, its drivers, and its potential economic value.

The tailwater below El Vado Dam supports sport fly fishing, particularly in the autumn. We 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.

10.4.1. Blue Ribbon Status

Blue Ribbon fishery status is a recognition of the unusually high-quality angling opportunities. There does not appear to be a national standard of evaluation for these sites, so we use the criteria established by Utah's Blue Ribbon Fisheries Advisory Council as a rough guide to the flow-dependent qualities that could hypothetically contribute to Blue Ribbon status (Utah Blue Ribbon Fisheries Advisory Council 2021). The four major criteria include fish quality, outdoor experience, habitat, and economic benefits. Some of these criteria are not relevant to this study; for example, the question of public access and accommodations is not one we address. We list the most relevant criteria below:

Utah Blue Ribbon Ranking Criteria:

- Can the fish population sustain increased pressure?
- Is [the fish population] a unique species or species assemblage?
- Is fish population augmented through stocking?
- Does natural reproduction provide significant input to [fish population]?
- Have special [fishing] regulations been established?
- Does this water have sufficient water quantity?
- Is the timing of water fluctuations and withdrawals affecting fish populations?
- Does water quality affect the fishery?
- Do anglers have the opportunity to catch and keep a lot of fish at this water?
- Do anglers have the opportunity to catch large fish at this water?

The overall economic effect expected from such an endeavor depends on the flow and water quality/turbidity changes to improve the fishery quality (see Harvey 2022 [Attachment] for discussion of the hydrograph that is needed to support fishery life cycles, and of how chronic turbidity affects the fishery, and how it might be reduced). How best to modify Rio Chama flows to enhance fish populations and angling enjoyment is a question of fish biology and hydrology rather than economics and is outside the scope of this report.

10.4.2. Dam Impacts on Fish Populations

In general terms, the impact of hydroelectric production on fish populations is mixed. Young et al. (2011) discuss the ways in which pulsed flow can improve or injure fish populations. Concerns related to high-flow periods are downstream displacement and the damage to populations that results from stranding fish or eggs on banks when water levels drop. However, pulsed flow can also provide spawning, hatching, and migration cues for some species. The degree of damage or benefit related to pulsed flows depends on local fish populations and conditions. The authors identify six knowledge gaps related to pulse flow effects:

the differences in impact related to different fish life stages, the impact on water quality (e.g., temperature or dissolved oxygen), the impact of habitat complexities, the long-term habitat changes related to pulsed flows, migration impacts, and the cumulative effects of small changes on populations over time.

10.4.3. Economic Valuation

Much of the non-market valuation research examining fishing improvements looks at the impact of river restoration, rather than river engineering. But there is some economic research on the impact of deliberately changing river conditions to optimize sport fishing.

Harpman et al. (1993) discuss the economic impact of changing streamflow to improve the adult brown trout population below Taylor Park Reservoir on the Taylor River in Colorado. The authors use a flow-driven aquatic population model to estimate the effects of changes in dam releases on the value of fishing assigned by anglers. This is based on an effective habitat framework drawn from USFWS's environmental modeling. They model the impact of changes in depth, velocity, and channel morphology on four trout life stages and use the resulting fish population profile to elicit willingness to pay from anglers in a dichotomous choice survey format. Similar to the Rio Chama valuation performed by Ward (1987), fishing values peak at under 500 cfs and decrease with higher flow values. The trout population was negatively impacted by no-flow periods and low-runoff years. The negative impact of low-runoff years seems to be tied to greater demand for agricultural water and less overall storage, rather than positive impacts from spring runoff itself. However, Harpman and co-authors find only a small positive economic impact resulting from improved trout populations. They theorize that this is due to the existing quality and quantity of fish in the area—the current fishing is of high-enough value that a marginal improvement has limited impact.

Hickey and Diaz (1999) also use a trout population model, SALMOD, to tie fishing quality to streamflow changes in the Cache La Poudre River basin. The model is substantially reliant on temperature and habitat modeling and incorporated significant site-specific calibration.

Their paper is notable in part because it uses a true optimization model to balance economic interests in the basin. However, it incorporates a monthly time-step, limiting its value in examining short-term flow fluctuations. The authors discovered that water scarcity between December and March results in a habitat bottleneck, significantly limiting the population of both brown and rainbow trout. They find that brown trout are almost twice as valued per catch as rainbow trout, due to their "superior cunning." Overall, they find that the increased costs of fishery-enhancing streamflows outweigh the benefits 10:1. This finding is overstated because the authors treat instream flows as consumptive rather than non-consumptive, and therefore count delayed water delivery as a total loss for municipal, industrial, and agricultural use. They do find a cooperative agreement framework results in benefits outweighing costs at very low constant streamflow alternatives.

The conclusions that can be drawn about a Blue Ribbon tailwater fishery in the Rio Chama are limited. This area would benefit from more direct research focused on the effect of streamflow changes on fish population dynamics. Habitat- and species-specific modeling is indicated. The fish habitat bottlenecks described by Hickey and Diaz in the Cache La Poudre River basin may also affect the Rio Chama, and this issue 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.

11. Conclusions

This study provides preliminary valuation for the Rio Chama system above Abiquiu Reservoir, which produces an average of $26 million in economic value every year, excluding Heron and Abiquiu Reservoirs. The majority 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.

There are several means of increasing the economic value of Rio Chama flows. Intraday flexibility in dam releases could increase the value of hydropower generated by between 3 and 10 percent. 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 modeled change results in an overall increase of about $900,000.

Important areas for further research include:

- **Reservoir recreation values.** Better data from visitors at Heron and El Vado Reservoirs would improve our understanding of visitor and spending patterns and their relationship with reservoir height. Heron Reservoir recreation is a substantial part of the value of the overall system, as the first scenario made clear. Decision-making based on this report should incorporate effects to Heron Reservoir. Further analysis should include extending economic valuation to fully incorporate recreation at Heron and Abiquiu Reservoirs, given the inevitable effect of flow management changes on those reservoirs and the disproportionate economic effect on reservoir recreation.

- **Environmental values.** Environmental valuation data was elusive. The model used in this analysis produced a small value for specific environmental outcomes based on the limited data available to tie specific environmental outcomes to flow patterns. This is almost certainly a gross underestimation of the true value of environmental services produced by the Rio Chama system. Adequate accounting for environmental components of value will require primary economic and environmental research on the Rio Chama. 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.

- **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. 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.

- **Environmental benefits for hydropower.** We also note a lack of information related to the indirect environmental benefits of hydropower. 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. This is an area that should be considered for primary research.

- **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.

Limitations of this study include its geographical constraints and modeling constraints. Value effects outside the study area are ignored. Short-term economic effects are modeled, but multi-year economic activity is not. Modeling focuses on measurable flow-dependent values, which may unduly emphasize some aspects of flow valuation. Recreational value numbers are based in a single study more than 30 years old. We rely on population and inflation adjustments to transform this data, but ultimately, we assume that this study is largely applicable to current New Mexico recreational behavior.

12. References

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