**Hydroelectric management on the Rio Chama:**
**Examining costs and benefits from non-consumptive flow management between the El Vado and Abiquiu reservoirs**

Student Researcher: Suzanne Stradling

Faculty Advisor: Dr. Janie Chermak

University of New Mexico
MSC05 3060, 1 UNM
Department of Economics
Albuquerque, NMM  87131
505-277-5304
stradlis@unm.edu

New Mexico WRRI Grant NMWRRI-SG-2018
Final report

## Introduction and Overview

The Rio Chama is a major tributary of the Rio Grande. Its headwaters are located in southern Colorado and the majority of the river lies in northern New Mexico, where it flows entirely within Rio Arriba County until it joins the Rio Grande at Ohkay Owingeh Pueblo. It features three large reservoirs: Heron Lake, El Vado Lake, and Abiquiu Lake.

The portion of the Rio Chama between Heron Lake and Abiquiu Lake provides non-consumptive recreation, power, and other environmental and economic benefits to the surrounding communities. Some of its uses can be valued using market prices, such as the electricity generated at the El Vado Dam, and some are not easily priced, such as the value visitors to the river or its reservoirs assign to those visits.

This study models the tradeoffs inherent in this connected system. A hydrological model of the system is used as a dynamic framework, and economic values are incorporated in order to calculate the total economic impact of flow variations as well as examine the individual tradeoffs that result (Morrison & Stone, 2015a). This economic valuation allows policymakers to better understand how changes in water policy can transfer the river's economic benefits between different groups or communities.

## Methodology

The project uses a combination of economic and hydrologic modeling to calculate an economic value for Rio Chama water under current conditions. The study also notes economic dimensions of value where data are unavailable or ambiguous.

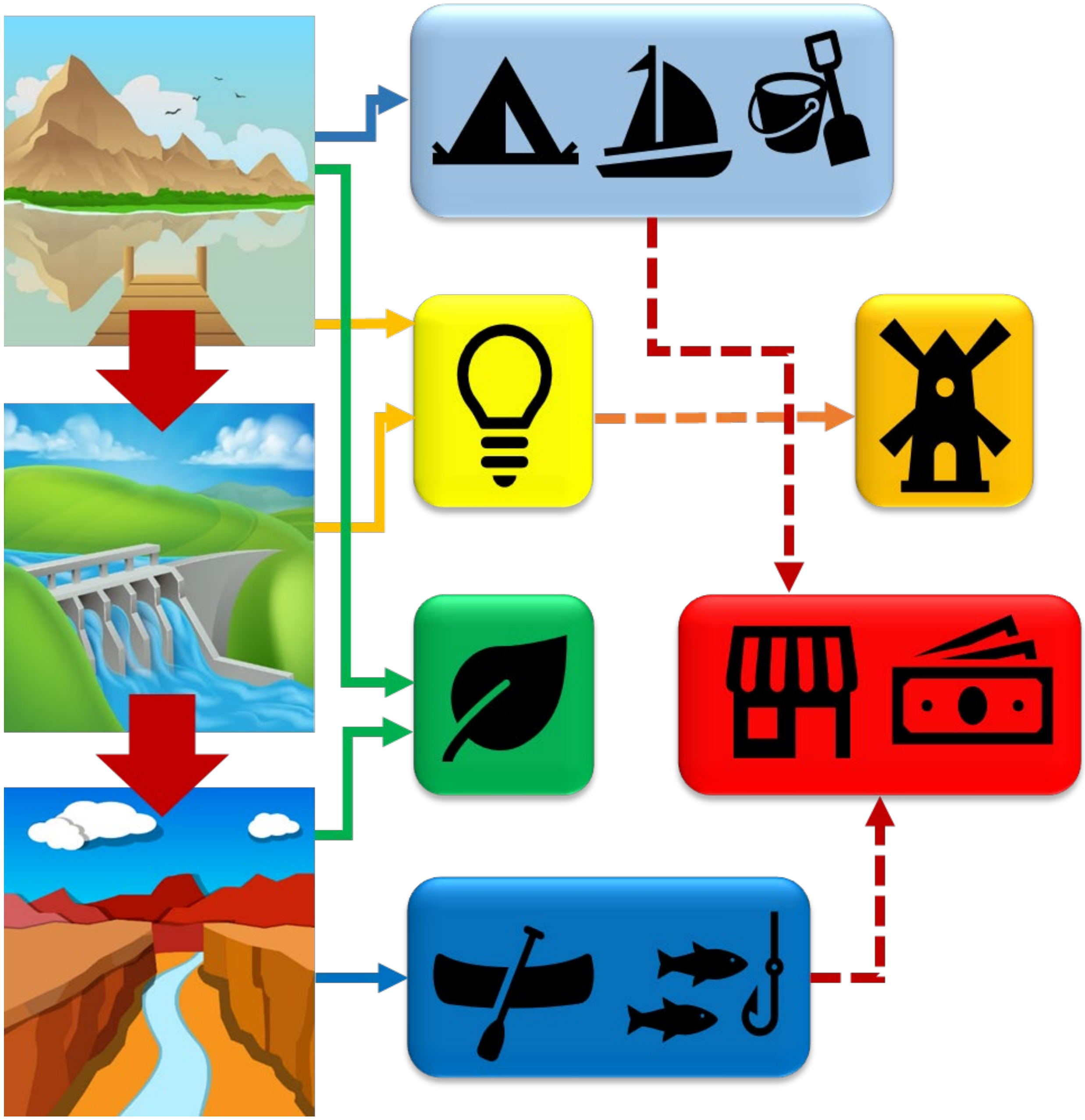
The economic impacts of the El Vado-Rio Chama system occur over different timeframes. They include short-term expenditures by visitors, which depend on daily conditions; non-use values, which are impacted by long-term trends; and electricity values, which change every five minutes. This study uses a baseline daily timestep, and sub-daily changes are represented by averages.

The study develops a cost-benefit framework incorporating six dimensions of value associated with the Rio Chama: the recreational value of the reservoirs, the recreational value of the river reach below El Vado Dam, the services and values associated with the ecosystem of the area, the value of hydropower produced by the dam, the indirect economic impacts of recreational visitors in the community and the indirect impacts of hydropower generation on availability of intermittent renewable electricity. These values are determined using benefit transfers from existing scholarship surrounding river and ecosystem uses and incorporated into the system model.

For recreation values, we conduct a benefit transfer using revealed preference data collected in the Rio Chama area in the 1980s and modified to reflect the area's changing population and economy (Booker & Ward, 1999; Ward, 1987). A lower bound for changes in ecosystem services value is derived from a benefit transfer from Weber and Stewart (2009). Hydropower valuation is based on publicly-available real-time power prices at the Four Corners power hub, published by the California Independent System Operator (CAISO). The impact of hydroelectricity availability on clean energy integration cannot be quantified based on existing published research, and a survey is developed to obtain more precise ecosystem services values and to examine public preferences for greenhouse gas reduction using hydroelectricity.

We use GoldSim software to produce a single-year Monte Carlo simulation of the system to calculate probable outcomes (GoldSim Technology Group, 2018). This incorporates statistical likelihoods to predict rainfall, waterflow, evaporation, and electricity prices. The result is a predicted range of values associated with changes in Rio Chama management.

FIGURE 1—INTERACTIONS WITHIN THE ECONOMIC MODEL



**Value dimensions**

The 34-mile stretch of the Rio Chama between El Vado Dam and Abiquiu reservoir is a popular rafting destination during the summer. El Vado's reservoir accommodates other recreational uses, such as boating and camping. Heron Lake, a reservoir about 2.5 miles upstream from El Vado, provides a place for sailing and hiking. All three areas are attractive sites for fishing and bird-watching.

The river and reservoirs also support a riparian ecosystem that provides a home for wildlife, including bald eagles and the New Mexico brown trout (New Mexico Energy, Minerals and Natural Resources Department, 2018). The reach below El Vado dam was designated part of the Wild and Scenic Rivers System in 1988, suggesting that it has "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values" to an extent that justifies federal action to preserve it in its undeveloped state (Wild and Scenic Rivers, 1968).

The river is managed by the U.S. Bureau of Reclamation. The river's natural flow is augmented at Heron Lake by an average 94,200 acre-feet of water provided through the San Juan-Chama Project (Utton Center, 2015). This water is transferred to the rights-holders downstream as they request it and must flow out of Heron Lake by the end of the calendar year.

The dam at Heron Lake does not have hydroelectric generation capacity. Both El Vado and Abiquiu dams have hydroelectric turbines owned by the Los Alamos County Department of Public Utilities (LACDPU). Currently, LACDPU regards these facilities as "run-of-the-river" dams; that is, they provide generation as water is released from the reservoirs, but LACDPU does not have the ability to time releases in order to generate electricity when needed (Utton Center, 2015). El Vado's generator has a nameplate capacity of 8.8 MW, and Abiquiu's generators have a nameplate capacity of 16.8 MW (S. Cummins, LACDPU, personal communication, April 13, 2018).

The Bureau of Reclamation and the City of Albuquerque work to meet the needs of local residents and visitors by modifying flow patterns to increase waterflows during summer weekends. This is intended to provide adequate streamflow for recreational rafting through the

Chama river gorge, a source of significant tourist revenue (Benson, Morrison, & Stone, 2013; Utton Center, 2015).

**Market Values: Hydroelectric Power**

Economic valuation of hydroelectric power is relatively straightforward, since the quantity of power produced is easy to measure, and power is sold in a competitive wholesale market with publicly-available prices. It is complicated by the variability of power prices: since power is usually consumed upon generation rather than stored, and power demand changes according to the time of day, prices can vary dramatically over a 24-hour period. These intraday variations are generally not reflected in retail electricity pricing, but they are an important component of hydropower benefits. This model uses daily average prices rather than intraday prices because there is no current policy of changing the flows at the El Vado Dam more than once in 24 hours.

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.

The value of hydroelectricity produced by the El Vado Dam can be simply modeled as a function of electricity multiplied by time-varying price:

$$V_{hydro} = P_t G_t$$

Price is exogenous and also varies over time. Hydropower generation ($G_t$) is a function of turbine efficiency ($C_{ef}$), gravity ($g$), water density ($\rho$), reservoir height or head ($H_t(R)$) which is a function of reservoir volume $R$, and waterflow ($Q_t$):

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

## Non-market Values: Reach Recreation

The economic value of recreation in the Rio Chama reach downstream of the El Vado Dam is primarily driven by fishing and rafting. Because this is a canyon in a wilderness area, access is limited. Fishing and rafting values are both use values, and we derive these values using benefit transfer from a travel cost analysis of the Rio Chama performed in 1981. Both fishing and rafting are feasible only under certain flow conditions, so user satisfaction is tied to waterflow patterns.

Ward (1987) uses travel cost methodology to separately determine fishing and rafting benefits on the stretch of the Rio Chama downstream of the El Vado Dam. This paper uses in-person interviews of 338 recreational visitors to the site over the summer of 1982. The researcher showed color photographs of different streamflow levels to the participant, who was asked to provide his or her 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 waterflows between 50 cfs and 4000 cfs.

### *Benefit transfer for use values and model framework*

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

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 modify the number of trips expected and therefore the number of miles traveled by recreational visitors. We show an overall increase in miles traveled of about 56% based primarily on increased population in Santa Fe, Bernalillo, and Taos counties. Using Consumer Price Index data, we adjust the value per mile traveled to 2017 dollars in order to compensate for inflation.

The model uses the daily values assigned by Ward. 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 do not attempt to incorporate weekday fishing or rafting values, which biases our results downward.

**TABLE 1: RANGE OF REACH RECREATION VALUES**

| | Value of reach recreation |
|---|---|
| 50% | $2,939,789.00 |
| 75% | $3,388,936.00 |
| 95% | $4,079,219.00 |

Ward does not incorporate streamside recreation use in his valuation. Since Daubert and Young (1981) find that streamside recreation is not responsive to flow changes, we do not attempt to quantify its value.

**TABLE 2—2017 ANNUAL AND DAILY BENEFITS ADJUSTED FOR POPULATION AND INFLATION**

| | Annual benefits | | | | Benefits per day | | |
|---|---|---|---|---|---|---|---|
| *Flow (cfs)* | *Fishing* | *Rafting* | *Sum* | *Flow (cfs)* | *Fishing* | *Rafting* | *Sum* |
| 50 | $1,118,527.79 | $0.00 | $1,118,527.79 | 50 | $16,947.39 | $0.00 | $16,947.39 |
| 100 | $1,494,400.84 | $0.00 | $1,494,400.84 | 100 | $22,642.44 | $0.00 | $22,642.44 |
| 250 | $1,640,767.97 | $0.00 | $1,640,767.97 | 250 | $24,860.12 | $0.00 | $24,860.12 |
| 500 | $2,056,144.02 | $0.00 | $2,056,144.02 | 500 | $31,153.70 | $0.00 | $31,153.70 |
| 1000 | $1,616,409.81 | $3,811,725.21 | $5,428,135.02 | 1000 | $24,491.06 | $86,630.12 | $111,121.18 |
| 2000 | $1,618,565.14 | $6,990,733.76 | $8,609,298.90 | 2000 | $24,523.71 | $158,880.31 | $183,404.03 |
| 4000 | $1,095,875.81 | $6,224,377.80 | $7,320,253.61 | 4000 | $16,604.18 | $141,463.13 | $158,067.31 |

**Non-market Values: Reservoir Recreation**

Because greater lake volume results in more shoreline and more lake surface, higher water levels are associated with greater recreational value (see Daugherty, Buckmeier, & Kokkanti, 2011; Hanson, Hatch, & Clonts, 2003; Neher, Duffield, & Patterson, 2013 among others). Ward (1986) find reservoir recreation value positively correlated with reservoir surface area but does not quantify the value associated with this recreational use. Reservoir recreational value is therefore modeled as

$$V_{reservoir} = b(R_t)$$

where $R_t$ is reservoir volume and the change in $R$ over time is modeled as $\dot{R} = h(Q_t)$.

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

Weekly recreational visitation numbers at El Vado Lake from July 2007 to June 2018 are provided by New Mexico State Parks[1]. Reservoir water elevation is drawn from Bureau of Reclamation data. Most park visitation takes place in June through September, while 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 does not reflect the true demand for park

[1] Personal communication, Cheryl Kolls, New Mexico State Parks NW Region Manager, Sept. 17, 2018.

**TABLE 3—RESERVOIR VISITOR SUMMARY STATISTICS**

*Average visitor count at El Vado Lake by month and year*

| Month | Obs | Average | SD | Min | Max | Year | Obs | Average | SD | Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *January* | 18 | 45 | (31) | 11 | 118 | *2007* | -- | -- | -- | -- | -- |
| *February* | 16 | 61.6 | (40) | 10 | 118 | *2008* | 25 | 1993.6 | (2,068) | 53 | 7730 |
| *March* | 19 | 131.1 | (165) | 5 | 663 | *2009* | 52 | 1281.5 | (1,693) | 6 | 7381 |
| *April* | 41 | 331.5 | (226) | 29 | 1241 | *2010* | 52 | 890.8 | (1,271) | 11 | 5343 |
| *May* | 45 | 911.8 | (684) | 96 | 3470 | *2011* | 50 | 1353.8 | (1,752) | 32 | 8839 |
| *June* | 41 | 2222.4 | (1,090) | 601 | 5343 | *2012* | 34 | 2151.2 | (1,850) | 253 | 8884 |
| *July* | 44 | 3514.4 | (2,060) | 1075 | 8884 | *2013* | 35 | 1419.3 | (1,093) | 318 | 5377 |
| *August* | 45 | 2421.3 | (1,079) | 690 | 5693 | *2014* | 34 | 1289.3 | (783) | 50 | 3553 |
| *September* | 42 | 1585.3 | (1,191) | 161 | 5033 | *2015* | 36 | 1417.5 | (1,428) | 95 | 8071 |
| *October* | 44 | 648.3 | (494) | 82 | 2174 | *2016* | 35 | 834.2 | (855) | 29 | 3980 |
| *November* | 44 | 414.5 | (252) | 29 | 946 | *2017* | 42 | 1028.8 | (1,163) | 13 | 4752 |
| *December* | 22 | 145.3 | (163) | 6 | 567 | *2018* | 26 | 368.4 | (517) | 5 | 1952 |

**TABLE 4—OLS REGRESSION**

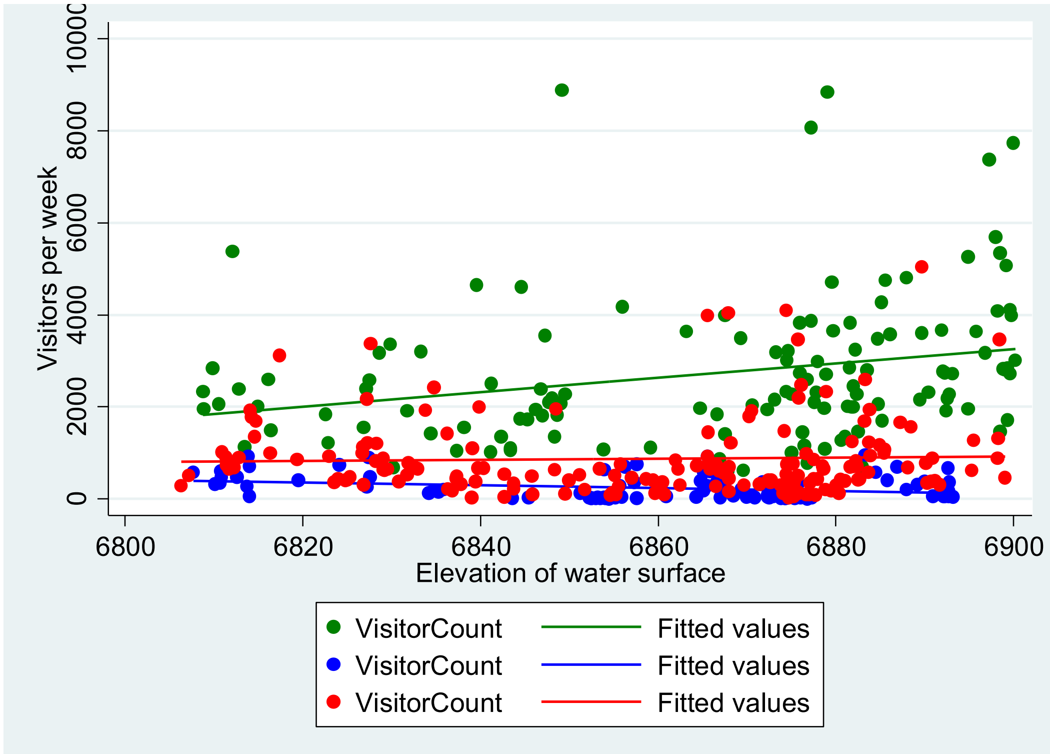
*Effect of water levels on visitor numbers at El Vado Lake*

| *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 |

visitation. Elevation data reveals 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 can observe waterflow-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. If we consider November through March the off-season, April and May as well

**CHART 2—RESERVOIR VISITORS BY WATER HEIGHT**




as September and October the shoulder season, and June through August the summer season, we can examine how reservoir volume impacts each group. Chart 2 illustrates the pattern observed. Winter (blue) and shoulder season (red) visitors are not responsive to changes in water height. However, summer visitors show an upward trend as water height increases. variation in average water elevation may result in fixed effects stripping some of the impact of low water from the regression.

However, when interaction variables between season 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. During the summer months, increased reservoir height and therefore volume is predictive of more reservoir recreation visits.

Although water elevation on its own is uncorrelated with visitor behavior, a one-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.

***Benefit transfer for use values***

There is no adequate benefit transfer to determine the dollar value of reservoir recreation enjoyed at El Vado Lake. Reservoir recreation includes gear-intensive activities like fishing and powerboating, so it cannot be assumed that rafting or fishing downstream is higher-value recreation. We therefore analyze three potential valuation rubrics for reservoir recreation, based on the value of reach recreation, discussed above.

Our lowest value possibility is that reservoir visitors value visiting El Vado approximately as much as the anglers, above, and come only from Rio Arriba County. 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. Because El Vado visitors both fish and use powerboats, the true value may be between the middle and high numbers.

TABLE 5—RESERVOIR RECREATION

| Value of reach recreation | | | |
|---|---|---|---|
| Baseline assumption | | Conservative assumption | |
| 5% | $0.00 | 5% | $0.000 |
| 25% | $67,306.00 | 25% | $11,374.71 |
| 50% | $95,215.00 | 50% | $16,091.34 |
| 75% | $200,724.00 | 75% | $33,922.36 |
| 95% | $311,975.00 | 95% | $52,723.78 |

## Non-market Values: 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 coauthors. 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 "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 or consumed (such as fish that have been caught or visits that have been experienced.)

The complexity of ecosystems makes it difficult to arrive at an absolute value for their services. We are limited by the scarcity of data about quantifiable ecosystem impacts that can be associated with flow pattern changes.

### *Benefit transfer for non-use values*

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 the target site. It 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 contingent valuation method and an alternative survey method, choice experiment, to calculate willingness to pay.

The Weber and Stewart survey is focused on the restoration of 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 waterflows in the spring months. Appropriate waterflow for cottonwood recruitment may or may not correlate with optimal or appropriate waterflow for other native species.

Weber and Stewart's survey discusses two endangered birds (the American Bald Eagle and the 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 the 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% 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 are listed in Table 5. It should be noted that the 95% confidence interval for increased wildland species population and overbank flooding crosses zero.

We use the decomposed values for restoration to apply to the Rio Chama study site. Waterflow 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 & Rosenberger, 2010), so this adjustment is an ad-hoc assumption based on the distance coefficient calculated in the source study: Weber and Stewart

**TABLE 5—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 |

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 richer 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% 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.

Individuals born in New Mexico have greater willingness to pay than individuals not born in New Mexico. Although 78.5% of people in Rio Arriba were born in New Mexico, compared to 46.7% in Albuquerque, we do not correct for this difference. This again biases our results downward. Since birth in New Mexico has a six-times greater upward impact on willingness to pay than income, the overall bias in the ecosystem valuation numbers 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.

The survey response rate for Weber and Stewart was very low, at 16.9%. 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% of households are willing to pay.

Finally, we assume that riparian recruitment success is binary, and we assign the full value when there is a 95% likelihood of successful recruitment in a given year. In other years, the value is zero. The baseline values associated with ecosystem services are provided in Table 6.

**TABLE 6—ECOSYSTEM SERVICES VALUES**

| Baseline assumption | | Conservative assumption | |
|---|---|---|---|
| 5% | $0.00 | 5% | $0.000 |
| 25% | $67,306.00 | 25% | $11,374.71 |
| 50% | $95,215.00 | 50% | $16,091.34 |
| 75% | $200,724.00 | 75% | $33,922.36 |
| 95% | $311,975.00 | 95% | $52,723.78 |

**Non-market Value: Support for renewable energy**

The 8.8 MW dam at El Vado is currently treated as a run-of-the-river dam, so water release decisions respond to water rights holders rather than being timed to electricity market demand or pricing. It is possible to change dam dispatch so that the dam produces more electricity during high-demand periods in the day. Because solar energy production decreases as demand increases in the evening, maximizing hydroelectric production during evening hours would support renewable integration into the grid (providing a flexible counterpart to intermittent renewable energy) and reduce greenhouse gas emissions as a consequence of replacing inefficient gas turbine generation during peak hours.

However, peak hour hydroelectric production has been associated with negative externalities in the reach below a dam due to water temperature, increased erosion, and changes in the natural system that are not optimal for area wildlife. Less hour-to-hour variability in waterflow improves riverine ecological outcomes.

The ecological impact of hydroelectric generation is not trivial. Moog (1993) discusses the impacts of short-term river flow changes attributable to dam operations on fish and invertebrates in an Austrian river. While the rivers in question have significant differences from New Mexico river systems, the paper does discuss flow change impacts on brown trout and other fish similar to the fish species present in the Rio Chama. The author examines river species that have been restocked and discovers significant downstream impacts with magnitudes negatively correlated to distance from the dam. In some cases, peak power flows are associated with 85% reduction in biomass. This seems tied to inadequate water in the river channel. Renöfält, Jansson, and Nilsson (2010) analyze this and subsequent studies to enumerate the ecological downsides of dams and the potential solutions for those problems. Their specific recommendations are intended for Swedish river systems, which are dissimilar to New Mexico rivers, and therefore they are of less interest than the authors' survey of potential ecological impacts attributable to dam flow variations. Poff and Schmidt (2016) also find that hourly flow changes have negative impacts on fish and insect reproductive cycles.

Quantifying the positive environmental impact of using hydropower to provide peak power is more difficult. 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. This paper discovers an 8.8% decrease in revenues when dam operation changes to reduce ecological impact on the riverine ecosystem. However, it 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.

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 flexibility of power sources. 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 US 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.

Jones and coauthors (2018) examine the relationship between these two issues. This paper discusses the outcome of a national contingent valuation survey with around 4000 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.

No research has been done on smaller dam systems and the dueling values of riverine ecosystems and clean air impacts. This survey is the first to quantify ecological values for the Rio Chama riverine system or for the greenhouse gas emission reduction associated with the El Vado Dam. It will provide guidance for the Bureau of Reclamation and the Rio Chama Flow Committee, which are reassessing flow management decisions for the river. It may also impact Bureau of Reclamation flow decisions associated with other small dams.

Existing research does not provide enough information to determine which environmental consideration should be prioritized. This study examines the ecological consequences of changing flows at the El Vado dam by asking individuals which of two flow options they prefer. Each flow option is associated with environmental benefits, but the two options are mutually exclusive.

### *Valuation Strategy: Survey*

Because of the lack of adequate information related to the indirect environmental benefits provided by using hydroelectricity to provide peak power, we are conducting a state-wide survey examining New Mexicans' attitudes and preferences when asked to choose between riverine ecology and cleaner electricity production. This survey should also provide better information about the value of the Rio Chama ecosystem than the benefit transfer performed based on Weber and Stewart.

The survey-taker will be asked whether they prefer for the dam to release water in a way similar to historical flow, which benefits the downstream ecosystem and its inhabitants, or whether they prefer the dam to release more water in the evenings, increasing electricity generation at a time when it will displace more polluting options and providing flexibility to the grid that supports solar panel installation. Net amount of daily waterflow does not change, because the options are designed not to impact use values associated with the reservoir and river.

This valuation question will discover which flow pattern is preferred by the public, and the public's willingness to pay for each of the two options. I expect that the value assigned to the riverine ecosystem will be inversely proportional to the distance from the river and will be correlated with individuals who use the area for recreation and are more familiar with the ecosystem. I expect that individuals with existing concerns about greenhouse gas emissions will have a higher willingness to pay for prioritizing evening hydroelectricity production. It is not clear how people with general environmental concerns will respond, since both options have positive and negative environmental impacts.

**Conclusions**

Results are preliminary at this time and omit indirect valuation altogether. The values derived for ecosystem services, based on benefit transfer, are anticipated to be replaced by direct data from the survey. Final data from the survey will be available in fall 2019 and will be communicated to WRRI at that time.

**Rio Chama Economic Values**

| | Mean | Confidence interval | | Standard Deviation |
|---|---|---|---|---|
| Total | $ 24,265,000.00 | $ 10,346,000.00 | $ 66,794,000.00 | |
| Hydropower | $ 1,292,000.00 | $ 1,282,000.00 | $ 1,301,000.00 | $ 182,363.00 |
| Reach recreation | $ 3,683,000.00 | $ 3,663,000.00 | $ 3,703,000.00 | $ 377,580.00 |
| Reservoir recreation | $ 19,290,000.00 | $ 5,401,000.00 | $ 61,790,000.00 | $ 553,039.00 |
| Ecosystem services | $ 97,552.00 | $ 94,052.00 | unknown | $ 67,225.00 |

Even at the minimum calculated value, reservoir recreation is the primary economic impact from the Rio Chama/El Vado system. This study was of limited scope and did not include the other two reservoirs on the Rio Chama, Heron Lake and Abiquiu Lake. Both these lakes also offer amenities for reservoir recreation, suggesting that the number obtained for El Vado is only a fraction of the total value of these reservoirs to New Mexicans.

We find that reservoir visitation is determined in part by reservoir height; however, we see significant year-to-year visitation variations that are not explained by reservoir conditions. Because of the economic importance of the reservoir, further research in this area is warranted.

Ecosystems services values are understudied. The unique characteristics of study sites limit the value of benefit transfer as a means of calculation. The values produced by this model are significantly less than the true value of the system, and this is likely to be true in most valuation scenarios. This may indicate routine undervaluing of ecosystems in cost-benefit and other analyses. Primary research in the Rio Chama area will produce more accurate numbers for New Mexico decision-makers and will inform other researchers working on similar valuation studies.

**References**:

Benson, M. H., Morrison, R. R., & Stone, M. C. (2013). A classification framework for running adaptive management rapids. *Ecology and Society*, *18*(3). https://doi.org/10.5751/ES-05707-180330

Booker, J. F., & Ward, F. A. (1999). Instream Flows and Endangers Species in an International River Basin: The Upper Rio Grande. *American Journal of Agricultural Economics*, *81*(5), 1262–1267.

Brown, T. C., Bergstrom, J. C., & Loomis, J. B. (2007). Defining, Valuing, and Providing Ecosystem Goods and Services. *Natural Resources Journal*, *47*, 329–376.

Daugherty, D. J., Buckmeier, D. L., & Kokkanti, P. K. (2011). Sensitivity of Recreational Access to Reservoir Water Level Variation: An Approach to Identify Future Access Needs in Reservoirs. *North American Journal of Fisheries Management*, *31*, 63–69. https://doi.org/10.1080/02755947.2011.559846

GoldSim Technology Group. (2018). GoldSim. Retrieved from https://www.goldsim.com/Web/Home/

Hanson, T. R., Hatch, L. U., & Clonts, H. C. (2003). Reservoir Water Level Impacts on Recreation , Property , and Nonuser Values. *Journal of the American Water Resources Association*, *38*(4), 1007–1018. https://doi.org/10.1111/j.1752-1688.2002.tb05541.x

Harpman, D. A. (1999). Assessing the Short-Run Economic Cost of Environmental Constraints on Hydropower Operations at Glen Canyon Dam. *Land Economics*, *75*(3), 390–401. Retrieved from http://content.ebscohost.com/ContentServer.asp?T=P&P=AN&K=0504846&S=R&D=eoh &EbscoContent=dGJyMMTo50Seprc4xNvgOLCmr1Cep7VSs6a4SraWxWXS&ContentCu

stomer=dGJyMPGqtk22qLNNuePfgeyx43zx

Henriot, A., & Glachant, J.-M. (2013). Melting-pots and salad bowls: The current debate on electricity market design for integration of intermittent RES. *Utilities Policy*, *27*, 57–64. https://doi.org/10.1016/J.JUP.2013.09.001

Johnston, R. J., & Rosenberger, R. S. (2010). Methods, trends and controversies in contemporary benefit transfer. *Journal of Economic Surveys*, *24*(3), 497–510. https://doi.org/10.1111/j.1467-6419.2009.00592.x

Jones, B. A., Berrens, R. P., Jenkins-Smith, H., Silva, C., Ripberger, J., Carlson, D., … Wehde, W. (2018). In search of an inclusive approach: Measuring non-market values for the effects of complex dam, hydroelectric and river system operations. *Energy Economics*, *69*, 225–236. https://doi.org/10.1016/J.ENECO.2017.11.024

Kaul, S., Boyle, K. J., Kuminoff, N. V, Parmeter, C. F., & Pope, J. C. (2013). What can we learn from benefit transfer errors? Evidence from 20 years of research on convergent validity. *Journal of Environmental Economics and Management*, *66*(1), 90–104. https://doi.org/10.1016/j.jeem.2013.03.001

Moog, O. (1993). Quantification of daily peak hydropower effects on aquatic fauna and management to minimize environmental impacts. *Regulated Rivers: Research & Management*. https://doi.org/10.1002/rrr.3450080105

Morrison, R. R., & Stone, M. C. (2015). Evaluating the impacts of environmental flow alternatives on reservoir and recreational operations using system dynamics modeling. *Journal of the American Water Resources Association*, *51*(1), 33–46. https://doi.org/10.1111/jawr.12231

Neher, C. J., Duffield, J. W., & Patterson, D. A. (2013). Lake and Reservoir Management

Modeling the influence of water levels on recreational use at lakes Mead and Powell Modeling the influence of water levels on recreational use at lakes Mead and Powell. *Lake and Reservoir Managment*, *29*, 233–246. https://doi.org/10.1080/10402381.2013.841784

New Mexico Energy Minerals and Natural Resources Department. (2018). El Vado Lake State Park. Retrieved November 8, 2018, from http://www.emnrd.state.nm.us/spd/elvadolakestatepark.html

Poff, N. L., & Schmidt, J. C. (2016). How dams can go with the flow. *Science*, *353*(6304), 1099–1100. https://doi.org/10.1126/science.aah4926

Renöfält, B. M., Jansson, R., & Nilsson, C. (2010). Effects of hydropower generation and opportunities for environmental flow management in Swedish riverine ecosystems. *Freshwater Biology*. https://doi.org/10.1111/j.1365-2427.2009.02241.x

Utton Transboundary Resource Center. (2015). *Water Matters!* Albuquerque. Retrieved from http://uttoncenter.unm.edu/pdfs/water-matters-2015/2015-water-matters.pdf

Ward, F. A. (1987). Economics of water allocation to instream uses in a fully appopriated river basin: Evidence from a New Mexico river basin. *Water Resources Research*, *23*(3), 381–392.

Weber, M. A., & Stewart, S. (2009). Public Values for River Restoration Options on the Middle Rio Grande. *Restoration Ecology*, *17*(6), 762–771. https://doi.org/10.1111/j.1526-100X.2008.00407.x

Wild and Scenic Rivers, Pub. 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