Economic impacts of federal policy responses to drought in the Rio Grande Basin

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[1] Significant growth in the Rio Grande Basin's demand for water has stressed the region's scarce water supply. This paper presents an analysis of the impacts of severe and sustained drought and of minimum in-stream flow requirements to support endangered species in the Rio Grande watershed. These impacts are investigated by modeling the physical and institutional constraints within the Rio Grande Basin and by identifying the hydrologic and economic responses of all major water users. Water supplies, which include all major tributaries, interbasin transfers, and hydrologically connected groundwater, are represented in a yearly time step. A nonlinear programming model is developed to maximize economic benefits subject to hydrologic and institutional constraints. Results indicate that drought produces considerable impacts on both agriculture and municipal and industrial (MI) uses in the Rio Grande watershed. In-stream flow requirements to support endangered species' habitat produce the largest impacts on agricultural water users in New Mexico and Texas. Hydrologic and economic impacts are more pronounced when in-stream flow requirements dictate larger quantities of water for endangered species' habitat. Higher in-stream flow requirements for endangered species in central New Mexico cause considerable losses to New Mexico agriculture above Elephant Butte Reservoir and to MI users in Albuquerque, New Mexico. Those same in-stream flow requirements reduce drought damages to New Mexico agriculture below Elephant Butte Reservoir and reduce the severity of drought damages to MI users in El Paso, Texas. Results provide a framework for formulating federal policy responses to drought in the Rio Grande Basin.

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1. Introduction

[2] Increasing population and growing demands placed on water resources of the Upper Rio Grande Basin (Figure 1) are magnifying probable economic losses incurred during a series of drought years. In this fully appropriated basin, even under normal flow conditions, water demands exceed supplies in the basin. Emerging demands for environmental protection in the form of in-stream flow for endangered species habitat further increases competition for already scarce water. In New Mexico, minimum in-stream flows and associated riparian habitats are critical to the preservation of the endangered Rio Grande Silvery Minnow (*Hybognathus amarus*), listed in 1994 by the U.S. Fish and Wildlife Service.

[3] The Rio Grande watershed consists of 180,000 square miles, including portions of three U.S. states and five Mexican states. From its headwaters high in the San Juan Mountains of southern Colorado, the Rio Grande travels about 1200 miles to the Gulf of Mexico, traversing the length of New Mexico and defining the U.S.-Mexico border downstream of El Paso, Texas. The Rio Grande watershed is topographically and geologically diverse. Its headwaters begin at about 14,000 feet at the Continental Divide in the San Juan range of the southern Colorado Rockies. Descending to the southeast, the mainstream is fed by several tributary streams as it flows through the San Luis Valley of southern Colorado. Several tributaries, principally the Rio Chama, the Rio Puerco, and the Rio Salado, contribute to flows of the Rio Grande in New Mexico. The river enters Texas, 23 miles north of El Paso at an elevation of 4000 feet, and continues downstream defining the U.S.-Mexico border until it reaches the Gulf of Mexico.

[4] The river's flow, reservoir levels, and water use patterns are controlled by a network of dams, reservoirs, and diversions projects. In 1906, the U.S.-Mexico Treaty divided the river flows between the U.S. and Mexico. The Treaty provides that 60,000 acre-feet per year be delivered to Mexico. In 1938, the U.S. Congress approved the Rio Grande Compact [*Hinderlider et al.*, 1938], which divides the annual water flow among the three states of Colorado, New Mexico, and Texas. The Compact provides for two delivery points: the Lobatos Gage on the Rio Grande at the Colorado–New Mexico border where Colorado makes scheduled deliveries to New Mexico, and Elephant Butte reservoir where New Mexico makes scheduled deliveries to

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Figure 1. Rio Grande Basin above Fort Quitman, Texas.

Texas. Typically, Colorado is required to deliver 25–50% of the headwater flows generated by the Rio Grande watershed in Colorado. New Mexico must deliver 50–90% of the flow measured at the Otowi Gage to Texas, where New Mexico's deliveries to Texas are measured at Elephant Butte Reservoir. Each upstream state may accrue credits for overdelivery of water, and incurs debits for underdelivery. Each state's debits as well as its credits are subject to upper bounds.

[5] Water demands for municipal and industrial (MI) needs in the basin's three major cities (Albuquerque, New Mexico; El Paso, Texas; and Ciudad Juarez, Mexico) have historically been met largely by groundwater pumping. This pumping is unlikely to be sustainable at current withdrawal rates. Albuquerque plans to begin withdrawing and treating river surface water in the future, and El Paso is increasing its use of surface water [*Paso Del Norte Water Task Force*, 2001]. The federal government has been a key player in the development and delivery of western water since the early twentieth century. Through the Bureau of Reclamation and U.S Army Corps of Engineers, the federal government developed water supplies that encouraged settlement of the arid west and brought considerable acreage under irrigation in the Rio Grande Basin (Table 1).

[6] Considerable conflicts among water users have resulted from federal actions such as supplying water for endangered species' critical habitat. These conflicts have complicated policy tradeoffs in allocating water among demands for irrigated agriculture, endangered species protection, and municipal and industrial water supplies. In some cases, allocation of water to support endangered species' critical habitat has resulted in reduced supplies available for agriculture, a pattern likely to recur. One important question whose answer can inform future policy debates centers around the economic effect of federal actions that restrict access to irrigation water supplies and the accompanying losses to agricultural producers in the absence of federal disaster relief or other compensation. Several proposals have been advanced that would substitute money or other resources for lost water to mitigate damages suffered by agriculture from water shortages.

[7] This paper's objective is to evaluate and identify the economic and hydrologic impacts in the Rio Grande basin of policy measures for addressing severe drought and endangered species' minimum in-stream flows. Information provided by meeting these objectives can be used to evaluate impacts of policies that would alter current farm water supplies or water use patterns. This information helps policy analysts to evaluate impacts of policy proposals and to design more effective policy responses to water shortages. The incremental (marginal) value of any use of water is the economic value gained (lost) if one extra acre-foot per year is supplied (lost) to that use. Marginal values per incremental unit of use can be compared across water policy proposals, for example comparing the value of water in agriculture versus cities versus endangered species critical habitat. *Ward and Michelsen* [2002] reviewed the literature on methods for measuring the economic value of water in irrigated agriculture. *Ward and Booker* [2003] analyzed the benefits and costs to agriculture and MI water users in the Rio Grande Basin from policy decisions that set aside in-stream flow requirements for endangered species.

[8] Having less water to use in agriculture because of drought or endangered species requirements may lead farmers to make changes in their irrigation practices. These changes can include changing the mix of crops they grow on their land, idling land, changing their water application methods, and in some cases, investing in irrigation equipment such as sprinkler or drip systems. Few of these changes occur without changes in costs, and many economic analyses of water reallocations around the irrigated west have been conducted in recent years. Table 1 summarizes farm size and irrigated acreage for the four major irrigated areas in the upper Rio Grande Basin: (1) Rio Grande Water Conservation District (RGWCD) in Colorado's San Luis Valley, (2) the Middle Rio Grande Conservancy District (MRGCD) in central New Mexico, (2) the Elephant Butte Irrigation District (EBID) in southern New Mexico, and (4) the El Paso County Water Improvement District 1 (EPCWID) in far west Texas.

[9] Water users in the Rio Grande Basin confront similar challenges faced by many of the world's rivers that support economies and cultures in dry places. Previous research has described policy challenges in the Sacramento and Colorado, United States [*Christensen et al.*, 2004; *Holland and Moore*, 2003; *Mahmoud and Garcia*, 2000; *Newlin et al.*, 2002]; Yangtze, China [*Guo et al.*, 2000; *Li et al.*, 2001; *Liu et al.*, 2003, 2004; *Nakamura*, 2003; *Yan and Qian*, 2004]; Jordan, Middle East [*Abu Zahra*, 2001, *Haddadin*, 2002; *Jagerskog*, 2003; *Mimi and Sawalhi*, 2003; *Shuval*, 2000]; Murray-Darling, Australia [*Arthington and Pusey*, 2003, *Keogh et al.*, 2004; *Quiggin*, 2001, *Reid and Brooks*, 2000]; and Nile, North Africa [*El-Kady and El-Shibini*, 2001; *Farah et al.*, 2000; *Kotb et al.*, 2000; *Strzepek*, 2000].

Table 1. Structure of Agriculture, Upper Rio Grande Basin, Colorado, New Mexico, and Texas[a]

Item	Colorado	New Mexico	New Mexico	Texas
District	Rio Grande Water Conservation District	Middle Rio Grande Conservancy District	Elephant Butte Irrigation District	El Paso County Water Improvement District 1
Counties	Rio Grande, Alamosa, Conejos, and Costilla	Sandoval, Bernallilo, Valencia, and Socorro	Sierra and Dona Ana	El Paso
Irrigated Land				
Farms	844	1,487	1,716	474
Acres	277,284	45,004	89,328	37,197
Farms by Value of Sales				
<$2500	391	1,251	803	290
$2500–$4999	93	214	293	78
$5000–$9999	131	186	244	55
$10,000–$24,999	191	179	203	58
$25,000–$49,999	171	77	107	17
$50,000–$99,999	115	62	74	35
$100,000 or more	269	102	190	67
Irrigated acres by farm size (2002)				
1–49 acres	1,661	9,510	8,192	2,795
50–99 acres	3,805	4,486	4,403	822
100–219 acres	13,540	4,753	9,882	7,578
220–499 acres	27,766	5,976	13,541	7,843
500–999 acres	76,833	941	16,759	10,064
1000–1999 acres	73,552	970	18,000	7,296
2000 acres or more	62,456	33,203	16,424	3,799

[a]Adapted from *2002 Census of Agriculture*, County Data, Tables 1 and 10 (available at http://www.nass.usda.gov/census/census02/volume1/index2.htm).

[10] Several studies have been completed since the mid 1990s that examine economic consequences to agriculture and to other water users of allocating scarce water to protect endangered species, in-stream flows, and other environmental needs. *Gillig et al.* [2001] examined economic-environmental tradeoffs through development of an integrated hydrological, economic, and environmental model of the Edwards Aquifer in Texas. *Green and O'Connor* [2001] examined water banking as a method to secure endangered species habitat in the Snake River. *Huppert* [1999] examined economic costs of recovering the endangered Snake River Salmon. *Keplinger et al.* [1998] examined payments required to reduce agricultural diversions from the Edwards Aquifer in Texas to promote environmental needs. *Moore et al.* [1996] analyzed tradeoffs between endangered fish species and irrigated agriculture for 17 western states. *Naeser and Smith* [1995] examined measures for securing in-stream flows to improve the aquatic environment in the Arkansas River, Colorado.

[11] A small body of research has examined the economic benefits of minimum in-stream flows, including papers by *Berrens et al.* [2000], *Brown* [2000] and *Hsu et al.* [1997]. *Paulsen and Wernstedt* [1995] analyzed the cost-effectiveness of various salmon recovery methods in the Columbia Basin. *Raffiee et al.* [1997] estimated economic costs of more than $160 million to increase by 2% the survival probability of an endangered Nevada fish. *Turner and Perry* [1997] examined least cost strategies for increasing in-stream flows for environmental benefits in Oregon's Deschutes River basin. *Willis et al.* [1998] examined measures to minimize economic damages to irrigated agriculture associated with setting up a contingent water contract to protect three species of endangered salmon during critical low-flow periods.

[12] Despite the accomplishments of the above-cited studies, there remains a need to understand and manage the impacts of water allocations to agriculture and MI users when these actions are influenced by federal decisions. Potential reallocations of water from irrigated agriculture to endangered species protection have generated various proposals to address damages that might result from federal actions that restrict water supplies and to identify innovative methods to mitigate those impacts. Policy alternatives could include (1) insurance provision mechanisms, (2) agricultural water conservation policies, and (3) market mechanisms. Implementing each of these policies would require a considerable investment of resources. To support the formation of a more informed policy, this paper's objective is to estimate economic and hydrologic impacts of policy measures for addressing severe drought and minimum in-stream flow requirements by endangered species in the basin. These objectives are carried out by focusing on (1) the level of water use, (2) the allocation among water users, and (3) the economic impacts resulting under different scenarios of drought and minimum in-stream flows for the protection of the Rio Grande Silvery Minnow (silvery minnow). The unique contribution of the current study is to analyze a series of droughts and in-stream flow scenarios and their hydrologic and economic impacts on the Rio Grande water users. The hydrologic and economic analysis is performed by constructing series of scenarios that reflect (1) varying water supply conditions in the watershed as well as (2) several institutional rules for meeting endangered species streamflow requirements. While the hydrology and laws of the Rio Grande are unique, the methods developed for this study can be applied or extended to other basins.

2. Economic Concepts

2.1. Economics of Water Allocation

[13] Spatial Equilibrium (SE) analysis is a central element for this paper's analysis of the Rio Grande. By SE, we mean the upstream-downstream location of each water user has important implications to the basin for current uses and for

policies that would alter those uses. For example, an agricultural region upstream of a city produces different water use patterns and results in different economic benefits than if the farming region is located downstream of the city. SE principles can help understand the economics of water allocation among sectors in the watershed. Agricultural water demands are drought sensitive, typically falling in response to greater shortages in water supply as farmers invest in various water conserving actions. The SE used for this analysis is a general equilibrium model of the basin that optimizes total economic benefits derived from water use and estimates water use, water price, and economic benefits by sector. The basin model used for the current study is an economic model that allocates water to activities among several competing uses at various locations (Figures 1 and 2). The outputs are water allocations and regulated river flows that generate the maximum economic benefit across all water uses (or minimum economic loss from drought or streamflow requirements). It produces maximum consumer and producer surplus consistent with relevant hydrologic and institutional constraints.

[14] These economic concepts are used to conduct an analysis of water policy for the Rio Grande Basin by examining the case of the competing uses, agriculture and MI, which have different price elasticities of demand. The economic principle behind this observed fact is that MI users are typically willing and able to pay a higher price for water in the face of shortages, than is irrigated agriculture. Where total economic damages produced by water supply shortages are minimized, such as in the Rio Grande watershed, a reduction of the surface water flows caused by drought are shared unequally across users.

[15] These economic principles characterize the fundamental nature of the allocation decisions designed in this analysis to replicate the economics and institutions of the Rio Grande basin. Drought causes water supply to fall. In the face of supply reductions produced by drought, endangered species requirements, or federal response to either, principles of economic efficiency are used to allocate water shortages among regions and sectors.

2.2. Economic Value of Water

2.2.1. Agriculture

[16] The value of water for the basin's irrigation in Colorado is measured using a nonlinear programming model that maximizes annual net farm income for the Rio Grande Water Conservancy District (RGWCD) in the San Luis Valley, in which water supply conditions vary from 100 to 0% of a full allotment. Cropping patterns vary according to the amount of surface water that is available and whether groundwater pumping rights are owned by the producer. Total district acreage allocated to each crop and the related net returns from irrigation water are optimized using data on crop water production functions and on production costs for the major crops produced in the region. [*Dalsted et al.*, 1996; *Sperow*, 1998].

[17] Downstream of the Colorado–New Mexico state line, the agricultural economic analysis uses the same principles employed for the basin's southern Colorado region, but with less detailed accounting of the connection between surface water and groundwater hydrology. Here, the analysis predicts how cropping practices under full water supply conditions adjust to various degrees of drought severity and to various possible habitat requirements for the endangered silvery minnow. The basin's three major agricultural regions in New Mexico and west Texas described earlier were chosen for analysis.

[18] Income-maximizing farm behavior models are estimated and calibrated to produce optimized cropping patterns consistent with historical cropping patterns, this in the spirit of the positive mathematical programming approach described by *Howitt* [1995], *Martinez et al.* [1999], and *Heckellei and Britz* [2000]. Results of these income-maximizing models are based on constraints on available land in each major cropping area and by crop water production technologies, for which an income-maximizing crop allocation is selected for each of the three farming areas [*Ward et al.*, 2001; *Ward and Michelsen*, 2002]. More details are described by *Booker et al.* [2005].

2.2.2. Municipal and Industrial

[19] The empirical analysis for the current study for estimating drought's economic impact, measured as the willingness to pay by MI users to avoid drought damages, is based on earlier work by *Michelsen et al.* [1998]. In that study, seven study areas were selected. The highest price elasticity estimate was for summer landscape use (approximately -0.20). The present study adapted the empirical demand schedule findings from the earlier study described above to the climatic and demographic conditions of Albuquerque and El Paso [*Ward et al.*, 2001]. For each city, a linear demand schedule was defined to pass through the water use and price combination for 2003. The slope of each city's demand was defined to produce the known price elasticity and the 2003 combination of price and use.

[20] We used the integral of the marginal benefits of water use to measure total benefits of that use. A linear demand function results in a quadratic total benefits function, of which those total benefits are maximized at the level of water consumption that occurs at a zero price. For higher consumption levels than consumption at a zero price, marginal benefits of added water are negative. In conditions where water is scarce, a model that optimizes total benefits will assign water only to uses for which marginal benefits are positive. Additional details are presented by *Booker et al.* [2005].

3. Methods of Analysis

3.1. Basinwide Model

[21] Much of the Rio Grande watershed model used in this study was developed as a part of a larger study on severe and sustained drought and its impact on the water resources in the basin [*Ward et al.*, 2001]. That larger model was developed to bring the region's hydrology, economics, and institutions within a single framework for policy analysis.

[22] The analysis begins with hydrologic input data that are matched to the inflow points of the river. This represents the contribution of all sources of water in the basin, shown by the basin's schematic in Figure 2. The hydrologic data used in the model were observed average annual streamflows over the basin's period of record.

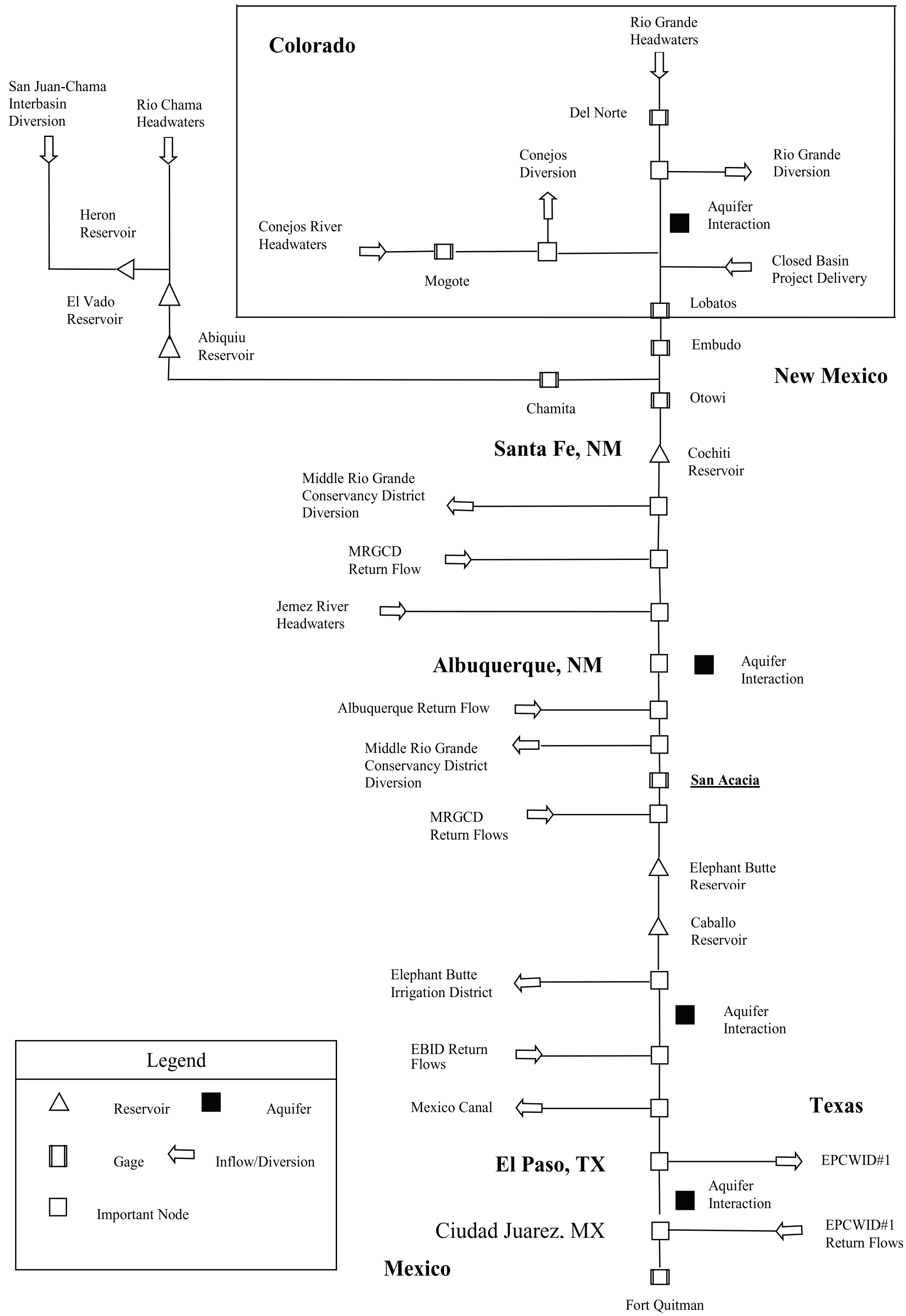

Figure 2. Schematic of the Upper Rio Grande Basin.

[23] The model accounts for decision processes made in both irrigated agriculture in the four major farming regions and by MI users in the two major U.S. cities in the Upper Rio Grande watershed. We simulate decisions of irrigators by constructing net farm decision models that maximize net farm income by choosing a crop mix and a quantity of surface and groundwater to use consistent with crop prices, crop yields, and farm production costs including the price and availability of both water sources. Surface supplies are reduced either from a more extreme drought or from

Table 2. Consumptive Uses of Water by Location in the Upper Rio Grande Basin

	Surface Diversion	Groundwater Pumping	Crop Use	MI Use	Surface Returns	Aquifer Returns
RGWCD Agriculture	Y	Y	Y	N	Y	Y
Albuquerque MI	N	Y	N	Y	Y	N
MRGCD Agriculture	Y	N	Y	N	Y	Y
EBID Agriculture	Y	Y	Y	N	Y	Y
El Paso MI	Y	Y	N	Y	Y	Y
El Paso Agriculture	Y	N	Y	N	Y	Y

reduced stream diversions required to maintain endangered species critical habitat. MI water use decisions are simulated through the price mechanism, in which information on changed supplies are revealed through price changes. Lower supplies are accommodated through reduced use in the face of increased prices.

[24] On the basis of estimated total benefits for each of the agricultural uses as well as for both MI uses, the analysis estimates the benefits associated with economically efficient allocations of water to those uses, consistent with the Rio Grande Compact and with the U.S. Mexico Treaty. Economic impacts of allocating water to support critical habitat for the silvery minnow at three different scenarios of in-stream flow levels are also analyzed. Table 2 shows the significant characteristics of consumptive uses at various locations in the basin. The symbol "Y" indicates that a particular characteristic is active, while "N" means the characteristic is inactive.

[25] The integrated framework of the Rio Grande basin model allows analysis of alternative water management institutions, i.e., institutions that characterize various rules for allocating water among the states, nations, and uses. The framework accounts also for physical interactions between uses (agricultural, MI, and environmental), at various geographical locations in the basin. Because of the importance of interstate and international water policy issues, relevant compacts, uses, storage, and flows are all represented. A detailed mathematical documentation of the model is given by *Booker et al.* [2005].

[26] Water supply reliability is an important water system performance indicator excluded by our model. Drought and ESA regulation will have an impact on average streamflows as well as on the reliability of those streamflows, and these impacts on reliability and will affect decision making. *Marques et al.* [2005] find that supply reliability has an important effect on agricultural production decisions, including the decision to adopt water-saving irrigation technology. *Lund* [1995] also found that reliability is important for urban water user's decision making. Measuring the economic damages from reduced water supply reliability on top of damages from reduced surface and groundwater supplies would increase overall damages produced by drought and endangered species requirements. Important future research needs to examine these effects of supply reliability to gain a more comprehensive set of impacts. The authors thank an anonymous referee for these insights.

[27] The treatment of native inflows, withdrawals, consumptive uses, reservoir storage, and compact and treaty institutional constraints are also defined. The model is coded in GAMS and is formulated as an optimization model whose objective is to maximize the total basin-wide economic benefits over each year subject to the physical, economic, and institutional constraints described above. Allocations under the Rio Grande Compact and Treaty were represented using the model. The Rio Grande Compact established schedules relating each state's obligation to the next state downstream on the basis of the upstream state's available water supply. The treaty obliges the United States to deliver annually 60,000 acre-feet to Mexico, except in periods of extraordinary drought. Therefore the model was heavily constrained by scarce water and the existing institutions defined by the Compact and by the Treaty.

3.2. Scenarios

3.2.1. In-Stream Flow Scenarios

[28] Economic costs are examined to both agricultural and MI water users associated with a variety of measures to assure year-round minimum flows for the silvery minnow. The expectation was that Albuquerque MI users and central New Mexico agricultural users would bear the greatest burden, while other users downstream might benefit from larger quantities of water released into Elephant Butte Reservoir from added in-stream flows assigned to keep the minnow from going extinct by protecting habitat. After the water passes the San Acacia reach near Socorro (Figures 1 and 2), it ends up in Elephant Butte Reservoir and is available for beneficial use for water users in southern New Mexico and west Texas. Average daily flows at the San Acacia gauge were converted to annual values. An important contribution of the present study is to parametrically vary the quantity of water at San Acacia reach near Socorro, New Mexico to represent various possible in-stream flow requirements needed to support the minnow's critical habitat.

[29] Permitting the quantity of water at the San Acacia reach to vary reflects current biological uncertainty regarding the minnow's habitat needs to assure survival of the species. It also permits an evaluation of the hydrologic and economic consequences of various levels of minimum flow requirements. This evaluation may be of interest to policy analysts who wish to know the consequences of various proposals for meeting endangered species habitat requirements.

[30] According to a recent report by the *U.S. Fish and Wildlife Service* [2005] the actual level of streamflow required by the silvery minnow is uncertain. While the silvery minnow does not need a large amount of water to survive, it does need an adequate quantity of flowing water to reduce prolonged periods of low flow or no flow, minimize the formation of isolated pools, and provide the minnow with a continuous food supply. Additionally, a spike in flow in the spring or summer to trigger spawning

and a relatively constant winter flow are required. The *U.S. Fish and Wildlife Service* [2005, p. 2] goes on to state that

> . . .the minnow needs sufficient flowing water with low to moderate currents capable of forming and maintaining a diversity of aquatic habitats, such as, but not limited to: backwaters, shallow side channels, pools, eddies, and runs of varying depth and velocity. These habitats are necessary to provide food, shelter, and conditions that allow the silvery minnow to reproduce and are usually found in areas with riverbed material made up of predominantly sand or silt. The silvery minnow also needs water of sufficient quality to maintain adequate water temperatures and water quality conditions.

In light of the considerable biological uncertainty surrounding streamflows requirements for the minnow, three possible in-stream flow delivery requirements were selected: 0, 50, and 100 cubic feet per second minimum year-round flows. These three levels were selected with the expectation they would bracket actual in-stream flow level found by biological analysis at some later date to be required by the minnow to guarantee the species' survival.

3.2.2. Drought Scenarios

[31] A series of drought scenarios was developed based on historical water flows at six major unimpaired headwater gauges. The drought scenarios were developed to reflect long-run average water supplies available to the Rio Grande Basin. Using long-run average streamflows at the six headwater gauges, drought scenarios were formulated to reflect a range of possible future water supplies available for use in the basin. The current study developed a series of constant scalars that were applied uniformly to all basin inflows. Various degrees of drought severity were simulated by varying basin inflows ranging from 100% to 50% of long-term averages at the six gauges. The constant scalars were the six coefficients, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 applied uniformly to all six headwater gauges. For example, a drought consisting of 80% of long-run average inflows was modeled by multiplying each of the six headwater gauges long-term average annual inflows by 0.8.

[32] Results reflect the combined impacts of drought severity and silvery minnow minimum flow scenarios on all major basin water users. This integration has considerable potential to more comprehensively account for the joint impact of drought and endangered species requirements, both of which can be intensified or controlled by federal actions.

4. Results

4.1. Overview

[33] Results summarize impacts of drought and silvery minnow flow constraints in the face of a single policy response: intrastate banking, in which shortages in each basin state are mitigated by a water marketing arrangement, in which potential buyers purchase water whenever the marginal value of water is higher for the buyer than for the seller. Typically the buyer is a city and the seller is agriculture. This policy has the effect of equalizing the marginal value of the added acre foot equal for MI and agricultural uses both within New Mexico and within Texas. The equalization of incremental benefits from additional water use among all trading partners assumes that there are no gains or losses in water to seepage or evaporation as the trades between partners occur.

[34] The model runs conducted for this analysis deleted all hydrologic gains or losses resulting from trades, for the purpose of bringing the economic results into sharper relief. This was done by setting to zero all return flows, seepage, evaporation, and groundwater pumping impacts on the river. This hydrologic simplification permits the economic value of water at the margin, to be equal at different points in the basin within each of the three states. Model runs that maximize the total economic value of the basin's water allocate water within each state so that marginal benefits are equal at different geographical locations, even though a considerable distance actually separates those uses. Deleting all hydrologic gains and losses means that no water is gained or lost solely because of long distances water must travel between uses in the basin. It also permits an spatial economic equilibrium to be reached among water users separated by large distances.

[35] While this simplification is hydrologically unrealistic, it was done to permit the economic analysis of drought impacts and in-stream flow requirements to be sharply separated from hydrologic impacts. A more extensive version of model has been developed in which return flows, seepage, evaporation, and groundwater pumping impacts on the river are all included [*Booker et al.*, 2005].

[36] Average gauged inflows to the basin for this period were 1.57 million acre-feet per year when summed over the six headwater gauges. For that time period, these average flows were: 659,800 acre-feet per year from the Rio Grande at the Del Norte gauge, 345,760 from the Conejos River, 439,000 from the Chama watershed, 45,170 from the Jemez River basin, 32,238 from the Rio Puerco basin, and 40,515 from the Rio Salado basin.

[37] For the baseline full water supply scenario, Colorado agriculture diverts about 678,000 acre-feet of surface water per year. Central New Mexico agriculture (NM_1), which includes the Middle Rio Grande Conservation District (MRGCD) above Elephant Butte Reservoir, diverts about 306,000 acre-feet, while Elephant Butte Irrigation District (EBID), diverts about 220,000 acre-feet surface water per year under full water supply conditions. For west Texas, long-run average annual agricultural water use is about 136,000 acre-feet of surface water.

[38] The sequence of drought scenarios, which represents a sequential decrease in the basin's water supply, shows a decrease in the water use for all agricultural users and results in a reduction of the long-run average water use for the three states' agriculture. Consistent with the Rio Grande Compact, Colorado agricultural water use is most affected by drought. Texas agriculture is least affected by drought, with New Mexico agriculture suffering intermediate losses in use. The small decrease in water use by MI in the Rio Grande watershed shown in Table 3 reflects the higher economic value of water use by MI compared to its value in irrigated agriculture. In fact, the City of El Paso has attempted in recent years to alleviate pressure on its depleting groundwater aquifer by shifting to a greater reliance of surface water through the development of surface treatment facilities. [*Paso del Norte Water Task Force*, 2001].

[39] Net income from New Mexico's irrigated agriculture above Elephant Butte Reservoir (NM_1) declines from just under \$10 million in normal water conditions by about \$6 million when surface flows decrease to 50% of normal.

Table 3. Impacts of Drought and Endangered Species Protection on Water Use in the Rio Grande River Basin on Absolute Levels of Water Use[a]

Drought and Minimum Flow Scenarios		Change in Water Use All Sectors, 1000 a-f/yr			Change in Water Use Agriculture, 1000 a-f/yr				Change in Water Use MI, 1000 a-f/yr	
Drought Conditions	Silvery Minnow Flows, cfs	CO	NM	TX	CO	NM_1	NM_2	TX	NM	TX
Baseline		0	0	0	0	0	0	0	0	0
50%	0	−265.10	−396.46	−119.79	−265.10	−206.52	−189.65	−119.31	−0.29	−0.48
50%	50	−265.10	−420.61	−95.63	−265.10	−268.83	−151.40	−95.25	−0.38	−0.38
50%	100	−265.10	−450.43	−65.82	−265.10	−307.00	−104.21	−65.56	−39.22	−0.26
60%	0	−201.00	−324.07	−100.00	−201.00	−165.53	−158.31	−99.60	−0.23	−0.40
60%	50	−201.00	−328.42	−95.63	−201.00	−176.77	−151.40	−95.25	−0.25	−0.38
60%	100	−201.00	−358.23	−65.82	−201.00	−253.66	−104.21	−65.56	−0.36	−0.26
70%	0	−142.50	−248.10	−78.21	−142.50	−124.06	−123.87	−77.90	−0.17	−0.31
70%	50	−142.50	−248.10	−78.21	−142.50	−124.06	−123.87	−77.90	−0.17	−0.31
70%	100	−142.50	−260.53	−65.86	−142.50	−156.10	−104.21	−65.60	−0.22	−0.26
80%	0	−89.50	−168.70	−54.41	−89.50	−82.45	−86.14	−54.20	−0.11	−0.21
80%	50	−89.50	−168.70	−54.41	−89.50	−82.45	−86.14	−54.20	−0.11	−0.21
80%	100	−89.50	−168.70	−54.41	−89.50	−82.45	−86.14	−54.20	−0.11	−0.21
90%	0	−42.00	−85.99	−28.41	−42.00	−41.02	−44.92	−28.30	−0.05	−0.11
90%	50	−42.00	−85.99	−28.41	−42.00	−41.02	−44.92	−28.30	−0.05	−0.11
90%	100	−42.00	−85.99	−28.41	−42.00	−41.02	−44.92	−28.30	−0.05	−0.11

[a]The baseline row contains zero absolute change in baseline water supply conditions, equal to 1.57 million acre-feet per year averaged gauged inflows per year summed over six headwater gauges. Zero silvery minnow flow means no instream flow protection for the endangered Rio Grande silvery minnow.

Agricultural water users in Colorado's San Luis Valley are affected by a severe drought defined by half of long-term inflows more in absolute terms ($158 million declining to $101 million in net income). However, the percentage of income lost by Colorado irrigators (36%) is much smaller than in New Mexico irrigators above Elephant Butte (61%) because of the terms of the Rio Grande Compact assigns a larger loss of streamflow under drought to New Mexico than to Colorado.

[40] Net income to New Mexico agricultural producers below Elephant Butte Reservoir falls from about $24 million by just over 40% to just over $13 million. Texas irrigated agriculture is hit especially hard by severe drought, suffering net income losses of about 81%. This magnified loss occurs because the Rio Grande Compact assigns a high percentage of drought-induced shortfalls to Texas, and because El Paso Texas MI users have a low price elasticity of demand for water compared to El Paso area irrigators. The majority of the water used for agriculture in the basin is from surface supply, although about 40% used in the San Luis Valley is from groundwater. Especially for the short term, the availability and use of groundwater by Colorado agriculture is the reason behind their economic resistance to the impact of drought.

4.2. Impacts of Drought and of Federal Endangered Species Protection

4.2.1. Hydrologic Impacts

[41] Table 3 shows the impact on water use in the basin resulting from a combination of five levels of drought and three levels of in-stream flow deliveries for endangered species protection. Under the Compact, New Mexico's contribution to minnow flows counts for increased credits or reduced debits to Texas. New Mexico must deliver to Texas a known quantity of water per year from Elephant Butte Reservoir based on the same year's total supply that flows past the Otowi stream gauge [*Ward and Booker*, 2003]. Because the Compact requires a known total delivery to Texas and because all minnow flows count for New Mexico's Compact deliveries to Texas, Table 3 shows that growing drought severity and deliveries needed to protect the minnow have a significant impact on the agricultural water use in New Mexico and Texas. However, the impacts on MI water use are generally small until the most severe drought is combined with the largest minnow flow deliveries required.

4.2.1.1. Agriculture

[42] Two significant patterns emerge for the case of the region's agriculture. First, water use by all four irrigation areas are strongly influenced by drought. For example, Colorado agriculture shows reductions in use ranging from 42 thousand acre-feet reduced use under mild drought conditions to about 265 thousand acre-feet reduced use under a severe drought falling to 50% of normal basin inflows. The other three irrigated areas also incur greater water use reductions in the face of droughts of greater severity.

[43] Second, the impact of in-stream flow deliveries for endangered species habitat is distributed quite differently among the four irrigation areas: Without additional state or federal legislation, water use by Colorado agriculture is not influenced at all by the in-stream flow delivery requirements for the minnow. By contrast water use by New Mexico agriculture above Elephant Butte Reservoir (NM_1) is reduced strongly by in-stream flow delivery needs over and above reductions in use produced by drought. This influence is more pronounced as drought worsens. For example, under the most severe drought, Table 3 shows that central New Mexico agriculture's water use falls by about 206 thousand acre-feet when there is no in-stream flow requirement downstream. However, it falls by 100% of its use from 307 thousand acre-feet to zero when 100 cfs of in-stream flow must be delivered downstream under the system's historical operation patterns. Both New Mexico agriculture below Elephant Butte Reservoir (NM_2) and Texas agriculture (TX) actually suffer smaller losses in use as in-stream flow requirements are increased, particularly when basin

Table 4. Impacts of Drought and Endangered Species Protection on Economic Benefit in the Rio Grande Basin[a]

Drought and Minimum Flow Scenarios		Change in Economic Benefits All Sectors, $1000/yr			Change in Economic Benefits Agriculture, $1000/yr				Change in Economic Benefits MI, $1000/yr	
Drought Conditions	Silvery Minnow Flows, cfs	CO	NM	TX	CO	NM_1	NM_2	TX	NM	TX
Baseline		0	0	0	0	0	0	0	0	0
50%	0	−56,430	−16,345	−6,503	−56,430	−6,041	−10,295	−6,477	−9	−26
50%	50	−56,430	−16,731	−4,612	−56,430	−9,415	−7,302	−4,594	−14	−18
50%	100	−56,430	−113,235	−2,683	−56,430	−9,857	−4,247	−2,672	−99,131	−11
60%	0	−42,173	−12,027	−4,932	−42,173	−4,213	−7,808	−4,912	−6	−20
60%	50	−42,173	−11,992	−4,613	−42,173	−4,683	−7,302	−4,594	−7	−19
60%	100	−42,173	−12,787	−2,683	−42,173	−8,528	−4,247	−2,672	−12	−11
70%	0	−29,491	−8,119	−3,432	−29,491	−2,681	−5,434	−3,418	−4	−14
70%	50	−29,491	−8,119	−3,432	−29,491	−2,681	−5,434	−3,418	−4	−14
70%	100	−29,491	−8,089	−2,683	−29,491	−3,836	−4,247	−2,672	−6	−11
80%	0	−18,290	−4,730	−2,061	−18,290	−1,464	−3,264	−2,053	−2	−8
80%	50	−18,290	−4,730	−2,061	−18,290	−1,464	−3,264	−2,053	−2	−8
80%	100	−18,290	−4,730	−2,061	−18,290	−1,464	−3,264	−2,053	−2	−8
90%	0	−8,485	−1,980	−890	−8,485	−570	−1,409	−886	−1	−4
90%	50	−8,485	−1,980	−890	−8,485	−570	−1,409	−886	−1	−4
90%	100	−8,485	−1,980	−890	−8,485	−570	−1,409	−886	−1	−4

[a]The baseline row shows total economic benefits unchanged compared to baseline water supply conditions. Those absolute economic values of water at the margin under base water supply conditions for each node are shown in Table 5. Other rows contain absolute changes in economic benefits. Negative signs refer to losses in benefits. Zero silvery minnow flow means no instream flow protection for the endangered Rio Grande silvery minnow.

inflows are the lowest. For example, both of these regions are seen to suffer much smaller drought losses in water use as in-stream flow delivery requirements are higher when inflows are at 50% of the long-run average.

4.2.1.2. MI

[44] Table 3 also shows the absolute change of the water consumptive uses in the Rio Grande basin by MI users due to the impact of drought and silvery minnow flows scenarios. Results shown in Table 3 show that the silvery minnow flow requirements and drought have comparatively minor effects on MI water use, with total MI use almost always being reduced by less than 1000 acre-feet compared to normal flow conditions without minnow flow protection. This small reduction occurs because of the very low price elasticity of demand for MI uses.

[45] Only in the lowest flow periods considered (50% of the total normal water supply) combined with the highest in-stream flow delivery requirements will MI users face appreciable reductions in water use. Even then, only New Mexico MI users are the ones who incur major water use reductions. This major use reduction occurs under the driest conditions combined with the highest in-stream flow requirements because there is no more water to be found from further reductions in agricultural use. All further reductions must come exclusively from reduced MI uses.

4.2.2. Economic Impacts

[46] Table 4 shows the loss in average annual economic benefits that would occur to both agriculture and to MI water use under the same 15 water supply scenarios. These scenarios include all combinations of five levels of drought and three levels of in-stream flow protection. Included in Table 4 are impacts to each sector and total impacts summed over both sectors split out separately for each of the three states.

4.2.2.1. Agriculture

[47] As was the case for hydrological impacts described in Table 3, two significant patterns again emerge for the case of economic impacts to the region's agriculture. First, agricultural net income in all four irrigation areas are strongly influenced by drought. For example, net income in Colorado agriculture incurs losses ranging from $8.5 million dollars the mildest drought conditions to $56.4 million under a severe drought falling to 50% of normal basin inflows. The other three irrigated areas also incur greater costs to net income resulting from reduced water use in the face of droughts of greater severity.

[48] Second, the impact on agricultural net income resulting from in-stream flow deliveries for endangered species habitat is distributed quite differently among the four irrigated areas: Without additional state or federal legislation, net income produced by Colorado agriculture is not influenced at all by the in-stream flow delivery requirements for the minnow. By contrast net income from water use by New Mexico agriculture above Elephant Butte Reservoir (NM_1) is reduced strongly by in-stream flow delivery needs over and above reductions in use produced by drought. This influence is stronger as drought worsens. For example, under the most severe drought, Table 4 shows that central New Mexico agriculture's net income falls by about $6.0 million when there is no in-stream flow requirement downstream. However, it falls by 100% of baseline level from $9.85 million to zero use when 100 cfs of in-stream flow must be delivered downstream under the system's historical operation patterns.

[49] Both New Mexico agriculture below Elephant Butte Reservoir (NM_2) and Texas agriculture (TX) actually suffer smaller economic losses as in-stream flow requirements are increased, particularly when basin inflows are the lowest. For example, both of these regions are seen to suffer much smaller economic losses to drought supply reductions use as in-stream flow delivery requirements are higher when inflows are at 50% of the long-run average. New Mexico agriculture below Elephant Butte Reservoir (NM_2) loses about $10 million under the most severe drought without

Table 5. Impacts of Drought and Endangered Species Protection on Water's Price in the Rio Grande Basin[a]

Drought and Minimum Flow Scenarios		Agriculture Price, \$/af				MI Price, \$/af	
Drought Conditions	Silvery Minnow Flows, cfs	CO	NM_1	NM_2	TX	NM	TX
Baseline[b]		200.08	10.15	24.24	24.24	10.15	24.24
50% of normal	0	225.65	48.39	84.33	84.33	48.39	84.33
50% of normal	50	225.65	59.93	72.21	72.21	59.93	59.93
50% of normal	100	225.65	67.00	57.26	57.26	5044.69	57.26
60% of normal	0	219.47	40.79	74.70	74.70	40.70	74.70
60% of normal	50	219.47	42.87	72.21	72.21	42.87	72.21
60% of normal	100	219.47	57.12	57.26	57.12	57.12	57.26
70% of normal	0	213.83	33.11	63.49	63.49	33.11	63.49
70% of normal	50	213.83	33.11	63.49	63.49	33.11	63.49
70% of normal	100	213.83	39.04	57.26	57.26	39.04	39.04
80% of normal	0	208.71	25.40	51.47	51.47	25.40	51.54
80% of normal	50	208.71	25.40	51.54	51.54	25.40	51.54
80% of normal	100	208.71	25.40	51.54	51.54	25.40	51.54
90% of normal	0	204.13	17.17	38.47	38.47	17.73	38.47
90% of normal	50	204.13	17.73	38.47	38.47	17.73	38.47
90% of normal	100	204.13	17.73	38.47	38.47	17.73	38.47

[a]Numbers report absolute water prices under the total supply defined by conditions for the row.
[b]Baseline is 100% of normal. This row reports the price of water under a full supply situation in which there are no flow requirements for the minnow. Price refers to the incremental economic benefits per additional acre foot.

upstream in-stream flow delivery requirements. However, when upstream appropriators must supply in-stream flows that end up in Elephant Butte Reservoir, those agricultural losses fall to about \$4.2 million. Similar results occur for West Texas agriculture.

4.2.2.2. MI

[50] Economic damages to the basin's MI users under the water supply scenarios follow a similar pattern as was produced by hydrological damages described in Table 3. Table 4 shows that water users in both Albuquerque and El Paso typically incur comparatively small costs from reacting to drought as well as from policies requiring in-stream flow protection for the silvery minnow.

[51] The exception to this finding is the very large cost of \$99.1 million incurred by Albuquerque water ratepayers when flows are provided for the minnow and drought inflows fall to 50% of long-run average. As stated previously, this very high loss of \$99.1 million in Albuquerque's ratepayers' economic benefit from reduced MI surface water under extreme drought conditions combined with a requirement that the minnow receive a minimum of 100 cfs at the San Acacia gauge year-round. This high economic loss occurs because agricultural water use has already fallen by 100% from about 307,000 acre-feet to nothing. Under these unusual conditions, there is no more water that can be made available from reduced agricultural diversions above Elephant Butte Reservoir under the system's current operation.

[52] After New Mexico has eliminated agricultural use in MRGCD on behalf of the minnow, the only remaining reductions will come from reduced MI use by City of Albuquerque water users. Under these unusual conditions of drought plus required minnow flows, when Albuquerque becomes dependent entirely on surface water, its use falls by an estimated 39,000 acre-feet compared to 84,390 acre-feet per year under normal conditions without a minnow flow requirement. When this set of conditions occurs, the incremental value of water is considerably higher for MI uses than for agriculture. For the remaining fourteen combinations of future water supply scenarios, total economic cost to MI water users is comparatively small in much the same as was total hydrologic cost was small and for much the same reason. The elasticity of demand is considerably lower for MI uses as for agricultural uses, so a small reduction in MI use produces an equal economic loss as a large reduction in agricultural use.

4.2.2.3. Both Sectors

[53] Table 5 shows the effect of the decrease on surface water supply in the Rio Grande watershed on water's price. For purposes of this study, the price of water is interpreted as the incremental (marginal) benefit of its use by any sector at any point in the basin. This price carries important policy implications: it measures the net income gained or lost by any water user at any point in the basin resulting from a one acre foot change in use. What this means is that any federal action that reduces a user's supply by one acre foot that reduces net income by \$25 would require a \$25 compensation to compensate that user economically. Each price shown in Table 5 is an estimate of the compensation that would be required to offset the economic losses per acre foot lost to the water user resulting from any action that reduces that use. Continuing with this example, when the tabled price of water is \$25, if 100 acre-feet are lost the minimum compensation required is $\$25 \times 100 = \$2500$.

[54] Prices shown in Table 5 are strictly correct only for a one acre foot change. Suppose the price is \$25 per single acre foot. If 100 acre-feet are lost then the compensation required to offset these nonmarginal losses are typically larger than \$2500. As larger amounts of water are lost, users will substitute other resources for water, and incremental values of water will increase beyond \$25.

[55] Table 5 shows that as the basin's inflows decrease, the price of water increases. However, for any basin inflow level the price of water is equal for all users in a given state. The equality of water's price for any given drought scenario among all users in a given Compact state occurs because the model is designed to maximize total regional returns subject to the water allocation constraint among the three states defined by the Rio Grande Compact. What this means is that water does not move across state lines consistent with

the Compact, but does move to its highest economic valued use within each state, most notably in New Mexico and Texas. When this trading occurs the marginal economic benefit from an additional acre foot supplied of water is equal among all users, which also results in an economically efficient water allocation occurring. The economically efficient pricing of water occurs when opportunities for trading water take place. This important contribution of neoclassical microeconomic theory facilitates the allocation of water from sectors with lower incremental economic value to sectors with higher incremental economic value.

[56] Still, when comparing incremental values of water from one state to the next, these prices are highly unequal under any water supply scenario. For example, Table 5 shows that New Mexico typically has the lowest incremental economic value of water in any water supply situation. This occurs because of comparatively low incomes produced by low levels of developed commercial agriculture in New Mexico above Elephant Butte Reservoir. Marginal economic values in the mid range occur in Texas, including New Mexico agricultural uses below Elephant Butte Reservoir. The highest value of water, at the margin occurs in Colorado's part of the basin, because of a long history of commercially productive profit-motivated capital intensive agriculture. Still, Colorado agriculture, despite its much higher marginal value than either Texas or New Mexico agriculture, produces a considerably lower value than does either New Mexico or Texas MI uses.

[57] Table 5 shows that under the baseline full flow conditions, the marginal value of an additional acre foot is about \$200 in Colorado, reflecting the low price elasticity of demand and high capital intensity of commercial agricultural production from irrigation in that region. The \$200 is an indication of the additional net income received by Colorado agricultural producers if one more acre foot of water could be found and put to beneficial use inside Colorado. That additional net farm income of about \$200 would result if Colorado's agricultural water use increased from 678,170 acre-feet to 678,171 acre-feet (Table 5). The \$200 is also an indication of the net income from irrigated agriculture that would be lost if supplies to the San Luis Valley fell by one acre foot, from 678,170 to 678,169 acre-feet.

[58] Table 5 also shows that as regional supplies are progressively reduced due to drought, the price of water (marginal value) always stays equal among competing users within each state, but all marginal values increase with reduced overall supplies to the basin. Thus when supplies fall to 50% of normal inflows, Colorado's marginal value rises to \$225 per acre foot, and New Mexico's agricultural and MI prices are equal at about \$48 per acre foot, while Texas' agricultural and MI prices are equal at about \$84 per acre foot.

[59] Equality of marginal values across sectors within each compact state amounts to assuming that intrastate water markets are established as a mechanism for allocating drought-induced shortages. Water trading among users occurs within each state, but not across state lines. If trading is not permitted, the marginal values will not be equal, and one would expect that marginal values will be lower in agriculture. Allowing the development of intrastate banks permits agricultural producers to increase their income by trading water for income. MI users trade money for water. Both get through a drought at a lower cost than either could without the market arrangement.

[60] Results show that as the river's basin inflows decrease or minnow flow requirements change, the price of water increases for all users. For each of the 15 water supply scenarios (for any given row), the marginal value of water is equal across all users in a given Compact state whenever there is some water use by all users (i.e., whenever there is an interior solution).

[61] One very interesting result of Table 5 is shown by the price of water being quite sensitive to the context in which its use occurs. For example, the marginal value of water in New Mexico agriculture above Elephant Butte Reservoir (NM_1) is typically lower than its equivalent value in New Mexico agriculture below Elephant Butte Reservoir (NM_2) or in Texas agriculture. Under baseline conditions the value of the additional acre foot is about \$10 in for NM_1 and about \$25 for NM_2 and Texas. However, this comparative ranking of values changes when the policy and drought context change. Notice that when 100 cfs of flow is required for the minnow under the most severe drought condition, the price of water for NM_1 increases rather dramatically to \$67 per acre foot, as all water is saved for the minnow by taking it from NM_1's agriculture. Likewise the much larger supply of water now available to NM_2 and Texas agriculture reduces both their marginal values to \$57.26. What this means is that even though central New Mexico agriculture produces lower marginal values than agriculture downstream of Elephant Butte Reservoir under normal conditions, when there is a large movement up or down the demand curve for agriculture due to large changes in water available for agriculture, water's price can change considerably.

5. Conclusions

[62] The objective of this study was to identify the hydrologic and economic impacts to the Rio Grande water users where federal actions could restrict access to water supplies. It was a response to the need of hydrologic and economic information regarding the economic feasibility of expanding crop insurance and noninsured crop assistance to producers where federal agency actions restrict access to irrigated water supplies. This analysis developed and applied an integrated model of hydrology, economics, and institutions of the Rio Grande watershed. Various reductions in water inflows to the watershed were analyzed to estimate hydrologic and economic impacts of series of both drought and in-stream flows scenarios to protect the endangered silvery minnow.

[63] Results indicate that drought is likely to have impacts on all water users in the Rio Grande watershed. When a drought becomes more severe, agriculture and MI water use in this basin will be affected, both by an increased cost of using water and by reduced supplies. Economic impacts to New Mexico agriculture were estimated at \$6 million per year above Elephant Butte Reservoir and \$10 million per year below the reservoir. This loss shows that drought will reduce net income to New Mexico's irrigated agriculture in the upper Rio Grande Basin by 61% above Elephant Butte Reservoir and by 43% below

the reservoir when surface water flows are reduced by 50% of normal. Agricultural income earned in southern Colorado is also strongly affected by drought in absolute terms (from an $8 million loss to an $56 million loss). However, Colorado irrigators suffer a smaller percentage loss than does either New Mexico or Texas irrigators. At the highest level of drought conditions, Texas agriculture loses more than 80% of its net income compared to that earned in a normal runoff year.

[64] One unique characteristics of the Rio Grande Compact relative to other western water compacts is that the Rio Grande Compact includes an explicit discussion of water quality. Article XI states:

> New Mexico and Texas agree that upon the effective date of this Compact all controversies between said States relative to the quantity or quality of the water of the Rio Grande are composed and settled; however, nothing herein shall be interpreted to prevent recourse by a signatory State to the Supreme Court of the United States for redress should the character or quality of the water, at the point of delivery, be changed hereafter by one signatory State to the injury of another. Nothing herein shall be construed as an admission by any signatory State that the use of water for irrigation causes increase of salinity for which the user is responsible in law.

An important limitation of this study is that preserving in-stream flows for habitat may have significant quality consequences that increase or decrease the benefits reported here. Protecting in-stream flows for the silvery minnow during dry years produces economic losses for both agriculture and MI uses of water in the Rio Grande watershed. The in-stream flows scenarios increase the economic losses that water users above Elephant Butte Reservoir in New Mexico experience during drought years. In-stream flow requirements have the largest impacts on agricultural water users in New Mexico and Texas. Hydrologic and economic impacts are more pronounced when in-stream flow requirements dictate larger quantities of water be reserved for endangered species habitat.

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