Effects of Water Supply Adjustments on Farm Returns and Resource Use: Findings from the Rio Grande Basin in Designing Federal Insurance Programs

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EXECUTIVE SUMMARY

The Rio Grande originates in the southern Colorado Rocky Mountains, flows through New Mexico, and forms the border between the U.S. and Mexico on its way to the Gulf of Mexico. Serving over one-million acres of irrigated land and the municipal and industrial needs of cities like Albuquerque and El Paso, the Rio Grande represents a significant resource in the arid southwest.

In 1938, Congress approved the Rio Grande Compact which divided the annual water flow among the three states of Colorado, New Mexico, and Texas. The U.S.-Mexico Treaty of 1906 divides the river flows between the U.S. and Mexico. The Compact acknowledges the Treaty in Articles IV and VI by stating that the Compact shall not diminish the allocation of water to Mexico and shall not degrade its quality.

Since that time, significant growth in the Rio Grande Basin’s demand for water due to increasing populations, growing economies, and emerging policies toward fish and wildlife habitat emphasizing endangered species, has stressed the region’s already scarce water supply. Although the inevitable severe drought would cause significant economic damage to the regional economy, present institutional arrangements have not had to confront such an event since the 1950s.

This study reports on an analysis of the impacts of severe and sustained drought and the impacts of minimum instream flow requirements to meet endangered species in the Rio Grande

watershed. These impacts were investigated by modeling the physical and institutional constraints within the Rio Grande Basin and identifying the hydrologic and economic responses of all major water users. This study estimated hydrologic impacts and economic costs associated with droughts and with various measures for providing adequate streamflow flow requirements to support survival of the endangered Rio Grande Silvery Minnow.

The general approach used in this study reflected the random supplies and uncertain demands for water. They also reflect river and reservoir management rules resulting from competing demands for water for M&I uses, agricultural demands, and needs for endangered species habitats. Water supplies, which included all major tributaries, interbasin transfers, and hydrologically connected groundwater, were represented in a yearly time-step. .

Agricultural water uses, the major source of water demands, were split into major crops for four major demand areas. Municipal and Industrial (M&I) demands were also identified for the Upper Rio Grande Basin's two major U.S. cities, Albuquerque, New Mexico, and El Paso, Texas. Demands for the endangered Rio Grande Silvery Minnow were identified as minimum streamflow requirements in the Rio Grande in central New Mexico. Separate economic values were identified for each water use at each major location. Information on the economic value of each water use at each location provides important facts to decision makers who wish to know impacts of complex proposals whose implementation affects several water uses at many locations.

A mathematical model was developed that kept track of economic benefits subject to hydrologic and institutional constraints, and was solved with GAMS optimization software. Results are presented as economic and hydrologic impacts of measures for coping with drought by state, economic sector, and institutional alternative for providing minimum flows for endangered species.

Total economic benefits were calculated for: (1) long run normal inflows, defined as 1.57 million acre feet per year, and (2) a sequence of drought inflows, defined by various percentage reduction in those normal inflows, from 90 percent (1.41 million acre feet) to 50 percent (0.78 million acre feet). Future economic growth in the population of Albuquerque and El Paso will increase the allocation of water to M&I uses and reduce the allocation to agriculture compared to results shown in this report.

Long-run annual average future drought damages, defined as the direct economic value of damages caused by the reduced streamflows to water users to 50 percent of normal inflows, were estimated at $56.4 million in lost direct farm income for the San Luis Valley, Colorado agriculture; $16.3 million for New Mexico irrigated agriculture; $8.7 million for Albuquerque, New Mexico M&I users; $6.5 million for west Texas irrigated agriculture; and $26.1 million for El Paso, Texas M&I users all of which would occur if zero instream flow deliveries are set aside for endangered species.

When instream flow requirements of 100 cfs of year-round streamflow in the Rio Grande mainstem at the San Acacia reach near Socorro New Mexico are set aside for endangered species, the level and regional distribution of long-run annual future drought damages take on a rather different look. Under those conditions, water losses induced by a severe drought of 50 percent of long-run average inflows produce the following economic damages: $56.4 million in lost direct farm income for San Luis Valley Colorado irrigated agriculture; $16.0 million for New Mexico irrigated agriculture; $99.1 million for Albuquerque M&I users; $2.6 million for west Texas irrigated agriculture; and $10.8 million for El Paso, Texas M&I users. Indirect economic impacts, resulting from interactions among drought-damaged water-users and related economic sectors, were not measured.

Results indicate that drought has severe impacts in all economic sectors in the Rio Grande watershed. Instream flow requirements have the largest impacts on agricultural water users in New Mexico and Texas. Hydrologic and economic impacts are more pronounced when instream flow requirements dictate larger quantities of water reserved for endangered species habitat. Higher instream flow requirements for endangered species in central New Mexico cause considerable losses to New Mexico agriculture above Elephant Butte Reservoir and to Albuquerque, New Mexico M&I users. Those same instream flow requirements reduce drought damages to New Mexico agriculture below Elephant Butte Reservoir and also reduce the severity of drought damages to El Paso M&I users. Both these drought damage reductions occur below Elephant Butte Reservoir because additional instream flow delivery requirements paid by New Mexico end up in Elephant Butte Reservoir, and are available for beneficial use below the reservoir.

Although the model used for this study is comprehensive and detailed, it has several limitations in its current state. Overall, it does not precisely represent the behavior of the Rio Grande Basin system, and many important hydrological relationships and complexities are simplified or excluded altogether. One special area where further improvement is needed is to develop a better understanding and modeling of connections among economics, surface water movement, groundwater hydrology, and behavior of water users.

For improved models to see future use to support development, execution, and evaluation of proposed water policies and institutions, considerable resources need to be put into the development, use, and testing of models. The kind of integrated, basin-wide modeling described in this report is a new area of research. The integrations required between modeling the behavior of water users and underlying natural processes are quite complex, poorly understood, and will require continued work, patience, and time to bring to full fruition.

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1 Introduction

Increasing population and growing demands placed on water resources of the Upper Rio Grande Basin (map, figure 1) are magnifying probable economic losses incurred during a series of drought years. Even under normal flow conditions, water demands exceed supplies in the basin. Emerging demand for environmental protection in the form of instream flow for endangered species habitat further increases competition for already scarce water. In New Mexico, minimum instream 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.

1.1 Background

The Rio Grande watershed contains 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 main stream 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. 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, which divided 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 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 over-delivery of water, and must incur debits for under-delivery. Each state's debits as well as its credits are subject to upper bounds.

Since the Rio Grande Compact was approved, significant growth in the basin's demand for water due to increasing populations, growing economies, and emerging policies toward endangered species has stressed the region's already scarce water supply. Still, conditions at the time the Compact was negotiated could not have predicted the growth in the basin's demand for water associated with a five-fold increase in regional population (Peach and Williams, 2000) or increased demands for streamflows to meet the habitat needs of endangered species.

The water demands for municipal and industrial (M&I) 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).

In the Rio Grande basin, each drought since the late nineteenth century has given rise to analysis of water problems, including questions regarding the adequacy of the water and institutional resources to meet the existing needs for water and actions intended to achieve a better balance between supply and demand for water in the future (Thomas, 1963). For example, the severe drought during 1951-57 was largely responsible for increased development of groundwater pumping and use of groundwater storage. The physical and institutional systems serving the Rio Grande watershed have a considerable but limited capacity for coping with severe drought (Ward et al., 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 (Table 1).

Intense 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 between 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 have resulted in reduced supplies available for agriculture, a pattern likely to recur.

Irrigated agriculture withdraws and consumes the most freshwater of any economic sector in the United States. It accounts for withdrawals of 150 million acre-feet (maf) nationally, or almost 40% of total freshwater withdrawals (Table 2). When measured by consumptive use, irrigation uses about 91 maf of water, or more than 80 percent of the total consumptive use. Most of this use occurs in the arid west where irrigated agriculture accounts for 133 maf, (75%) of total freshwater withdrawals, and 79 maf, (or almost 90%) of total water consumed regionally. Roughly two-thirds of the irrigation water in the west is supplied from surface water sources, with groundwater accounting for the remaining supply.

Where water is allocated to uses such as protecting endangered species or developing urban areas, this use typically will come from existing uses. Irrigated agriculture is often seen as a logical source of the water for other uses because of its high proportion of total existing use, ranging from 80 to 90 percent of total use in most of the irrigated west.

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.

Information on the total and incremental economic value of water in agriculture can be used to evaluate impacts of policies that would alter current farm water supplies or water use patterns. This information enables 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 M&I water users in the Rio Grande Basin from policy decisions that set aside instream flow requirements for endangered species.

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 irrigation 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 3 summarizes farm size and irrigated acreage for the four major irrigated areas in the upper Rio Grande Basin analyzed in this study: (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 (EBCWID) in far west Texas. (See Map in Figure 1).

Water users in the Rio Grande Basin confront similar challenges faced by many of the world's rivers that support economies and culture in dry places. Previous research has described policy challenges in the Sacramento and Colorado, US (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, Liu et al., 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);

More recently 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, instream flows, and other environmental needs. Gillig, McCarl 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, Mulville, et al. (1996) analyzed tradeoffs between endangered fish species and irrigated agriculture for the 17 western states.

Naeser and Smith (1995) examined measures for securing instream flows to improve the aquatic environment in the Arkansas River, Colorado. Paulsen and Wernstedt (1995) analyzed the cost-effectiveness of various salmon recovery methods in the Columbia Basin. Raffiee, Luo, et al. (1997) estimated economic costs of more than $160 million to increase by two percent the survival probability of an endangered Nevada fish. Turner and Perry (1997) examined least cost strategies for increasing instream flows for environmental benefits in the Oregon's Deschutes River basin. Willis, et al. (1998) looked for ways 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.

Despite the accomplishments of the above-cited studies, there remains a need to understand and manage the impacts of water allocations to agriculture and M&I 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.

The cost and consequences of providing insurance to farmers who face the risk of reduced access to irrigation water will depend in part on the insurance strategy and the mechanism used. Three examples are described. First is a subsidized insurance system, which current crop insurance programs could be modified, to protect participating farmers against certain weather and market-related shortfalls in crop yields and revenues. One alternative that could insure farmers against this risk is to alter the current crop insurance programs to include coverage of these potential losses. Another measure is direct compensation to farmers. This could occur in the event of irrigation water supply reductions in much the same way as Congress takes action in response to certain weather-related losses. A third method is tradable contingent bonds, in which the federal government could insure farmers through an auction of tradable bonds that pay a predetermined value in the event of reduced irrigation water supplies.

1.2 Objective

This study responds to the need for 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 study focuses on the Upper Rio Grande watershed (map, figure 1), in which the water allocation conflicts between irrigated agriculture and endangered are sustained and intense, especially in periods of drought. This study'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 instream flows. The study focuses 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 instream flows for the protection of the Rio Grande Silvery Minnow (silvery minnow).

2 Methods of Analysis

2.1 Economics of Water Allocation

Spatial Equilibrium (SE) analysis is a central element for analysis of the Rio Grande. 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. This SE optimizes total economic benefits derived from water use and estimates water use, price, and sector economic benefits.

The Rio Grande basin SE model used for the current study is an economic model that allocates water to activities among several competing uses at various locations. The outputs of these models 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), i.e., maximum consumer and producer surplus consistent with various hydrologic and institutional constraints.

The economic principles at work in the Rio Grande basin model can be understood by considering Figure 2, which shows a supply (S) and demand (D) schedule for a specified water use. The demand schedule results from water users optimizing their use of water and describes how the marginal value of water in this activity falls with increased quantities of water used. The total value of water in this activity (i.e. the users' total willingness to pay for water) is measured by the shaded area under the demand curve up to the quantity consumed.

Consumer surplus is defined by the total willingness-to-pay less the total amount paid, where total amount paid is price multiplied by quantity. In a similar fashion, the supply schedule describes the marginal resource costs (benefits displaced) required to supply a given quantity of water. Total resource costs are measured by the area below the supply curve. Total producer surplus is equal to the amount paid to the producer who supplies the water less total resource costs. If the supply curve (S) includes all benefits displaced by supplying water to the given user at a given time and place, total economic benefit is maximized at the intersection of supply and demand (Q*), where marginal benefits equal marginal opportunity costs. This allocation can be achieved in a market setting or under other institutional arrangements. At this optimum, consumer surplus is shown by the area (ghP*) and producer surplus shown by the area (iP*h).

The introduction of water supply constraints, produced by various drought scenarios, alters the efficient allocation. When river water is limited and insufficient to reach Q*, marginal benefits (MB) may exceed marginal costs (MC). This difference is defined as:

$$\lambda = MB - MC.$$

This value is the implicit marginal value or shadow price of water and reflects the net economic value of an additional unit of water to the system, if that additional unit of water can be developed and put to beneficial use. In figure 3, suppose initially that the available surface water results in a shadow price equal to λ_0. At this price, water use is Q_0 at the point where the shadow price equals the net marginal value of that use. A decrease in the surface water availability increases the shadow price of water to λ_1, and results in a lower level of water use at Q_1. The change in economic benefits associated with this reduction in surface water is measured by the shaded area, which is the change in consumer and producer surplus.

To conduct an analysis of water policy for the Rio Grande basin, these economic concepts are used to examine the case of the competing uses – agriculture and M&I – which have different demand elasticities. Figure 3 shows two demand curves, D_1 and D_2, that represent agriculture and M&I which compete for a fixed water supply. The horizontal sum of these demands is the total demand curve (shown in bold), for which total water supply is shown as S. Initially, the shadow price of water in the system (incremental value of one more unit supplied) is equal to λ_0, and total water use is equal to Q_0. The share of the total allocated to each use is determined by setting the market demand price (P_0) equal to quantities demanded summed from the two individual demands. This allocation process assigns Q_{10} to M&I and Q_{20} to agriculture.

When drought reduces the surface water supply, the shadow price increases to λ_1, total water use falls to Q_1, and total demand price rises to P_1. Equating this new price with the quantities demanded at that price to each of the two individual uses results in a greater reduction in the more price-elastic use (agriculture), D_2. Compare the large water use reduction by agriculture, $Q_{20} - Q_{21}$, with that of the M&I, $Q_{10} - Q_{11}$. A greater share of original water use is retained in the use with the lower price elasticities (M&I sector). The economic principle behind this observed fact is that M&I users are typically willing and able to pay a higher price for water in the face of shortages, than is irrigated agriculture. The shaded area in Figure 3 shows the net change in consumer and producer surplus associated with the decrease in the surface water supply. These results show that 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 not shared equally across users.

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 responses to either, this analysis uses the principles of economically efficient resource allocation described above to allocate water shortages among regions and sectors.

2.2 Economic Value of Water

2.2.1 Agriculture

For the Colorado region, the economic value of Basin water was determined using a two-stage optimization model that maximizes annual agricultural income in the San Luis Valley for various possible annual water supply conditions. Water supply conditions were defined by: (1) the quantity of water in the aquifer and (2) total annual streamflow in the Rio Grande available for use in Colorado. The allocation of water by water right priority was addressed in the first stage of the model, which allocated streamflow from the Rio Grande to irrigation ditches and canals holding the highest priorities. Cropping patterns were dependent upon the amount of surface water available and whether groundwater pumping rights are owned by the producer. Those patterns and the associated net returns from irrigation water are estimated in the second stage of the model based upon crop production functions and costs of production for the major crops produced in the study area (Dalsted, *et al.*, 1996; Sperow, 1998).

Downstream in New Mexico and West Texas, the agricultural analysis used similar methods as in the Colorado region, but with less detailed accounting of the explicit interaction between the economics and hydrology of surface water and groundwater. It is based upon estimating how cropping practices under full water supply conditions adapt to various degrees of drought severity. As described previously, all three of the basin's major agricultural regions in New

Mexico and west Texas were chosen for analysis: (1) Middle Rio Grande Conservancy District (MRGCD) near Albuquerque, New Mexico; (2) Elephant Butte Irrigation District (EBID) near Las Cruces, New Mexico; and (3) El Paso County Water Improvement District No. 1 (EP#1) near El Paso, Texas. For each of these three farming areas, agricultural prices, yields, and production costs were incorporated for the area's most important crops. The analysis is based on farm cost and return enterprise budgets published by New Mexico State University and Texas A&M University. For each area, a linear programming model was developed and applied to represent behavior of commercial producers that maximize net returns, using standard methods for valuing water in agriculture (e.g., Ward and Michelsen, 2002). Income-maximizing farm behavior is based on historical cropping patterns and is limited by constraints on available land by cropping area, and by crop-water production technologies (Ward, et. al, 2001).

A total of 49 combinations of surface water and groundwater supplies were considered, ranging from a full supply of three acre feet per acre of surface water and three acre feet of groundwater to zero of both. All drought response data points for all irrigation regions are available from the authors on request. The dependent variable for the regression model was total agricultural net income per acre, while the independent variable was per-acre quantity of surface water diverted. Benefit functions under various water supply conditions for these four irrigation regions are summarized by Appendix Table 1.

2.2.2 Municipal and Industrial

The use of water produces considerable economic value in a modern household. Beyond satisfying basic human requirements, water has been extensively analyzed as an economic resource for which there is a considerable urban demand, particularly in the desert southwest. Similarly, water shortages resulting from drought cause economic damages for which people are willing to pay considerable amounts to avoid. Besides cooking, washing, cleaning and sanitation, the typical Rio Grande Basin household in the U.S. uses water for outdoor cleaning and to sustain a domestic landscape environment. The empirical analysis for the current study for estimating drought's economic impact[1] is based on earlier work by Michelsen *et al.* (1998). In that study, seven study areas were selected. With cooperation of water utilities in California, Colorado, and New Mexico, information was collected on residential water use, rate structures, revenues from water sold and non-price conservation programs covering the period from 1980 through mid-1994.[2] Across seven cities, water's demand was found to be quite price inelastic.[3]

The highest price elasticity estimate was for summer landscape use (approximately -0.20). The current study applied the empirical demand schedule findings to the climatic and demographic conditions of Albuquerque and El Paso (Ward *et al.*, 2001) with benefit function parameters summarized in Appendix Table 1. 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

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[1] That impact is measured as the willingness to pay to avoid drought damages.

[2] The original study area cities were: Los Angeles and San Diego, California; Broomfield and Denver, Colorado; and Albuquerque, Las Cruces and Santa Fe, New Mexico. Similarities and differences in residential water use, prices and rate structures, climatic conditions and demographic characteristics of people who live in those areas provides an excellent cross-section of factual data for cities in the southwestern United States.

[3] A price inelastic demand means that a large percentage increases in price are required to induce small percentage decreases in water use.

defined to produce the known price elasticity and the 2003 combination of price and use.[4]

2.3 Hydrologic-Economic Model of the Upper Rio Grande Watershed

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.

The unique contribution of the current study is to analyze a series of droughts and instream flow scenarios and their hydrologic and economic impacts on the Rio Grande water users. The hydrologic and economic analysis was performed by constructing series of scenarios that reflect (1) varying water supply conditions in the watershed as well as (2) several institutional rules for dealing with endangered species requirements. Neither of these two analyses were performed under the work cited above on severe or sustained drought.

The analysis begins with hydrologic input data that are matched to the inflow points of the river which represent the contribution of all sources of water in the basin, shown in figure 4 by the basin's schematic. The hydrologic data used in the model were observed average annual streamflows over the basin's period of record.

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[4] For a known price elasticity, the slope of a linear demand curve can be determined once the price and quantity are known. We used the integral of the marginal benefits of water use to measure total benefits of that use. A linear demand function produces a quadratic total benefits function, of which those total benefits peak at the level of water consumption produced by a zero price. For higher consumption levels, marginal benefits of additional water are negative. When water is scarce, a model that optimizes total benefits will assign water to only to uses for which marginal benefits are positive.

The model accounts for decision processes made in both irrigated agriculture in the four major farming regions and by M&I users in the two major U.S. cities in the Upper Rio Grande watershed. Based on estimated total benefits for each of the agricultural uses as well as for both M&I 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 instream flow levels are also analyzed. Table 4 shows the significant characteristics of consumptive uses at various locations in the basin. Pluses indicate that a particular characteristic is active and minus means the characteristic is inactive.

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, M&I, 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 in Ward et al. (2001) and in Ward and Booker (2003).

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 (General Algebraic Modeling System) and is described in detail (Ward et al., 2001). The model 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 of the Rio Grande Compact and 1906 United States/Mexico Treaty.

2.4 Scenarios

2.4.1 Instream Flow Scenarios

Economic costs are examined to both agricultural and M&I water users associated with a variety of measures to assure year round minimum flows for the silvery minnow. The expectations were that Albuquerque M&I 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 instream flows assigned to keep the minnow from going extinct by protecting habitat. After the water passes the San Acacia reach, it ends up in Elephant Butte Reservoir and is available for beneficial use for water users in southern New Mexico and west Texas.

The San Acacia gauge was chosen as the point to measure required minnow flows. 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 (figure 1) to represent various possible instream flow requirements needed to support the minnow's critical habitat. 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. Three possible instream flow delivery requirements were selected: 0, 50, and 100 cubic feet per second minimum year-round flows. These three levels were selected to bracket the actual instream flow level likely to be chosen to assure the species' survival.

2.4.2 Drought Scenarios

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 (figures 5-10), drought scenarios were formulated to reflect a range of possible future water supplies available for use in the basin. An important contribution of the current study is the development of a series of constant scalars that could be applied uniformly to all basin inflows. Basin inflows range from 100 percent to 50 percent of long term averages at the six gauges. 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.

3 Results

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 keeping the marginal value of the added acre foot equal for M&I and agricultural uses both within New Mexico and within Texas.[5] If no actual intrastate water market materialized, actual losses could be larger or smaller than those indicated in the tables below, depending on which users reduced use of how much water.

Findings are presented in three sections. First, results are shown for varying drought scenarios where no special provision is made for the endangered species flow requirements. Second, findings are shown for the case of providing different levels of instream flows for the endangered species. Under a severe drought scenario of basin inflows falling to half of long term averages, results are shown for both varying levels of drought as well as varying levels of instream flow

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[5] 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. The model runs conducted for this study deleted all hydrologic gains or losses resulting from trades, for the purpose of bringing the economic results into sharper relief. While this is not hydrologically realistic, it was done this way to permit the economic analysis of drought impacts and instream flow requirements to be clearly 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 (Ward and Booker, 2003).

delivery requirements. In all cases, results are shown both for water use patterns and for the economic impacts produced by those water use patterns.

3.1 Impacts of Drought

3.1.1 Hydrologic Impact

3.1.1.1 Agriculture

Table 5 shows the total water consumptive use by diversions and the percentage change of water used for the agricultural sector for each state within the watershed and for multiple scenarios of drought intensity. Baseline inflows to the system are long-run average inflows for the basin's period of record. Impacts are based on multiple drought scenarios combined with no instream flow deliveries for the minnow.

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 three Conejos Index gauges, 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.

For the baseline full water supply scenario, Colorado agriculture diverts about 678,000 acre feet of surface water per year. Central New Mexico agriculture (NM1), 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.

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 reduced use of the long run average water use for the three states’ agriculture. Colorado agricultural water use is least affected by drought, which occurs because of the provisions of the Rio Grande Compact. Texas agriculture is the most affected by drought, with New Mexico agriculture suffering intermediate economic losses.

3.1.1.2 Municipal and Industrial (M&I)

Table 6 shows the water consumptive use by M&I diversions and the percentage change in water use on each state within the basin and for multiple drought scenarios. New Mexico is represented by Albuquerque M&I use which, through groundwater pumping, effectively diverts from the river an annual average at about 84,000 acre feet. For Texas, long-run, average water use is about 75,000 acre feet. Colorado has no M&I diversions.

The table shows that the multiple drought scenarios have only a slight affect on the level of water diverted by both Albuquerque and El Paso M&I users. As the region's aquifers are mined, these and other cities will look increasingly to surface water to meet their needs, especially in periods of drought. Diversions of water for irrigation and municipal use claim nearly 80 to 90 percent of the Rio Grande’s average annual flow.

Water rights claims to the Rio Grande's annual streamflow exceed its annual supply by a factor of at least ten. In the upper watershed, new municipal diversions always represent a greater demand for water. More than 75 percent of the basin's population lives in the Santa Fe, Albuquerque, Las Cruces, and El Paso metropolitan areas, some of the fastest growing communities in the nation. Currently, El Paso and Albuquerque draw 40 and 100 percent of their water, respectively, from groundwater aquifers. Faced with severe declines in these aquifers and population pressure, both cities have proposed major water projects to draw drinking water from the river. Their plans call for the cities to draw up to 50 percent of their water from the river by 2005, possibly removing an additional 100,000 acre-feet of water from a river that already runs dry periodically.

The City of Albuquerque plans to develop capacity to treat and divert surface water from the Rio Grande, based on its San Juan-Chama Project water rights. This will be a major component of its future water supply. But San Juan-Chama water will not meet municipal needs indefinitely. Populations can be expected to continue to grow, and cities will be required to look for other sources of water.

The small decrease in water use by M&I in the Rio Grande watershed shown in the table reflects the higher economic value of water use by M&I 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).

Since the Rio Grande surface water is fully or over-appropriated in much of the basin, new appropriations will unlikely be available to meet future urban needs. Thus it is likely that water for urban growth will be met through conversion of agricultural water rights. This has happened throughout the west since the early 1900s, when a growing Los Angeles looked to the farms of the Owens Valley to meet its growing demands for water.

3.1.2 Economic Impact

3.1.2.1 Agriculture

The structural systems and institutions supplying water in the three basin states are distinct but linked. Therefore, the economic impact of drought scenarios is likely to be shared unequally among the three states and two sectors. The river's operating procedure, which we describe here as the Law of the River, is governed largely by the Rio Grande Compact and U.S. Mexico Treaty. This Law of the River, while defining clear rules for sharing shortages, does not claim to produce water allocations that minimize total economic damages to the region.

Table 7 shows the change from the baseline in economic benefits produced by agricultural sector water use patterns under several drought scenarios and without guaranteed minnow flows at the San Acacia reach. We distinguish between results shown for each state’s agricultural use to highlight some important economic and institutional features within the basin. The right hand set of columns show the percentage change in economic benefits produced by agricultural water uses in the basin.

Net income from New Mexico's irrigated agriculture above Elephant Butte Reservoir (NM1) declines from just under $10 million in normal water conditions by about $6 million when surface flows decrease to 50 percent of normal. 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 percent) is much smaller than in New Mexico irrigators above elephant Butte (61 percent) because of the terms of the Rio Grande Compact assigns a larger loss of streamflow under drought to New Mexico than to Colorado.

Net income to New Mexico agricultural producers below Elephant Butte Reservoir falls from about $24 million by just over 40 percent to just over $13 million. Texas irrigated agriculture is hit especially hard by severe drought, suffering net income losses of about 81 percent. This magnified loss occurs because the Rio Grande Compact assigns a high percentage of drought-induced shortfalls to Texas, and because El Paso Texas M&I 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 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.

3.1.2.2 M&I

The economic responses to change in drought scenarios for the M&I users are shown in Table 8. Reduced water supply in the Rio Grande basin produces no major economic impact on the M&I

users of the basin. These results are the benefits produced by the M&I under the institution of the current Law of the River when total future inflow to the basin matches the average streamflow into the basin over the historical period of record.

According to the hydrologic and economic results shown in previous tables, it is clear that agricultural water uses are the most affected sector in the basin by drought measured in absolute reductions of water use. By comparison, M&I users incur little use reductions even if the supply of the surface water decreases by half as long as large instream flows for the minnow are not required on top of shortfalls produced by drought. This difference in sharing unequally the impact of drought can be explained by the nature of the demand function of each sector. In most of the irrigated west, use of water by irrigated agriculture is quite sensitive to price: small increases in the price of water produce a great reduction in quantities used for irrigation.

3.1.2.3 Both Sectors

Table 9 shows the affect 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 will require a $25 compensation to compensate that user economically. Each price shown in table 9 is an estimate of the compensation 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 x 100 = $2500.[6]

The table shows that as the river's basin 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 (Rio Grande 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 (defined by the Compact), but does move to its highest economic valued use within each state, most notably New Mexico and Texas. When this trading occurs the price (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 when opportunities for trading water for cash occur, an 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.

Still, when comparing incremental values of water from one state to the next, these prices are

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[6] It's important to note that prices shown in the table are strictly correct only for a one acre foot change. Suppose the price is $25 per single acre foot. Now, if 100 acre feet are lost the compensation required to offset these non-marginal 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.

highly unequal under any water supply scenario. For example Table 9 shows that New Mexico typically has the lowest incremental economic value of water in any water supply situation. This occurs because of comparatively 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 active and productive agriculture.[7]

The table 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 level 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 southern 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. Appendix Table 1 shows the benefit function used for Colorado agriculture as well as the benefit functions used for the all other major diverters.

The table 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

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[7] However, Colorado agriculture, despite its much higher marginal value than either Texas or New Mexico agriculture, has a considerably lower value than does either New Mexico or Texas M&I uses.

marginal values increase with reduced overall supplies to the basin. Thus when supplies fall to 50 percent of normal inflows, Colorado's marginal value rises to \$225 per acre foot, and New Mexico's agricultural and M&I prices are equal at about \$48 per acre foot, while Texas' agricultural and M&I prices are equal at about \$84 per acre foot.[8]

3.2 Impacts of Endangered Species Protection

The following section presents the hydrologic and economic impacts of providing minimum flow to the silvery minnow. Results are shown both for water use patterns and for economic benefits produced by those water use patterns, agriculture and M&I. The term "use" always means beneficial use from surface water diversions (no ground water use or interaction with the surface water system).

3.2.1 Hydrologic Impact

3.2.1.1 Agriculture

Table 10 shows agricultural water use patterns in the Rio Grande basin that would occur with guaranteed minnow flows in the driest scenario (50 percent of normal river flow). Under the present system operation, these minnow flows could be delivered by a reduction of stream depletions of up to about 2,500 acre feet in dry years (Ward and Booker, 2003).

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[8] 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. M&I users trade money for water. Both get through a drought at a lower cost than either could without the market arrangement.

The table summarizes the absolute and the percentage change on agricultural water consumptive use and on every minimum flow scenario. The four agricultural water users respond by a decrease in their water use (comparing to the baseline level) as the minimum flow requirement takes a higher level. In this scenario, Colorado agriculture water users are unaffected by the policy of meeting endangered species habitat in New Mexico because Colorado's delivery requirements under the Rio Grande Compact are not influenced by New Mexico's minnow flow requirements. Therefore, all decreases in Colorado agricultural water use shown in the table solely influenced by drought and not at all affected by instream flow requirements.

Agricultural water use in New Mexico above Elephant Butte Reservoir (NM_1) falls considerably in a drought period in which basin inflows are reduced to 50 percent of long run average. Moreover that use by New Mexico's agriculture is reduced even more as instream flow delivery requirements for the minnow increase. As year round minnow flow requirements increase from 0 to 50 to 100 cfs, that part of New Mexico's agricultural water use decreases by 67 percent, 87 percent, and 100 percent respectively under the river's current operating rules.

Agricultural water use in New Mexico below Elephant Butte Reservoir (NM_2) falls even more in the face of a drought severe enough to reduce basin inflows to 50 percent of normal because those users absorb a greater part of the basin's water shortages under the Compact. However, remarkably, reductions in use by those New Mexico irrigators are smaller as instream flow delivery requirements to the minnow increase. As year round minnow flow requirements increase from 0 to 50 to 100 cfs, southern New Mexico's agricultural water use (EBID users) decreases by 86 percent, 68 percent, and 47 percent respectively under the river's current operating rules. This moderation of drought losses faced by EBID users occurs because increased upstream minnow flow requirements are met through reduced agricultural diversions. These reduced diversions leave more water available to flow downstream to Elephant Butte Reservoir, and hence more water is available for beneficial use by EBID irrigators.

Agricultural water use by west Texas irrigators experience a similar moderation in water use reductions from drought in the face of greater instream flow deliveries for the minnow made above Elephant Butte. As year round minnow flow requirements increase from 0 to 50 to 100 cfs, the table shows that west Texas agriculture water use decreases by 87 percent, 70 percent, and 48 percent respectively under the river's current operating rules.

3.2.1.2 M&I

Table 11 shows M&I water use patterns in the Rio Grande basin in the driest drought scenario, defined as 50 percent of normal long term flow, combined with various potential guaranteed minnow flows. The table summarizes the absolute and the percentage change on M&I water use for each of five minimum streamflow scenarios. The two major M&I water users respond by decreasing their water use in the face of severe drought and in the face of progressively higher minimum flow requirements for the minnow.

There are no M&I water users in Colorado's section of the Rio Grande Basin that influence flows in the river, since those flows are influenced almost solely by agricultural use. M&I water use in

New Mexico by the City of Albuquerque falls a modest 290 acre feet per year a drought period in which basin inflows are reduced to 50 percent of long run average with no special provision for minimum flows compared to a baseline water use of about 84,000 acre feet per year. This modest reduction in use occurs because the price elasticity of demand for M&I use by Albuquerque never exceeds -0.20 in absolute terms. This considerably low price elasticity compared to elasticities for agriculture results in a total benefits function from water uses by M&I uses that rises very steeply (large and positive B_1), and , then falls steeply as per household saturation is reached (large negative B_2) (Appendix Table 1)

For the severe drought shown in the table, water use by Albuquerque M&I is reduced more as instream flow delivery requirements for the minnow increase downstream of Albuquerque. As year round minnow flow requirements increase from 0 to 50 to 100 cfs, the table shows that part of New Mexico's M&I water use decreases by 0.34 percent, 0.45 percent, and quite remarkably 46.47 percent under the river's current operating rules. The very high reduction in Albuquerque's M&I surface water use at 100 cfs required for the minnow occurs because agricultural water use has already fallen by 100 percent and there is no more water from reduced New Mexico agriculture available above Elephant Butte Reservoir. After New Mexico has eliminated agricultural use on behalf of the minnow, the only remaining reductions would come from reduced M&I use. Under these extreme conditions, if Albuquerque is dependent entirely on surface water, its use falls by an estimated 39,000 acre feet to provide required flows for the minnow.[9]

M&I water use below Elephant Butte Reservoir for El Paso Texas falls even more in the face of a drought severe enough to reduce basin inflows to 50 percent of normal because Texas users absorb a greater part of the basin's water shortages under the Compact than do New Mexico users. This is shown by the larger absolute reduction in use (480 acre feet) and percentage reduction in use (-0.63 percent) incurred by El Paso compared to Albuquerque M&I users. However, for a given drought, El Paso's use reductions are actually smaller as instream flow requirements are increased upstream of Elephant Butte Reservoir. This occurs for the same reasons as agricultural reductions below Elephant Butte Reservoir were smaller than agricultural use reductions above the reservoir: more water delivered into the reservoir means more available for beneficial M&I uses below the reservoir.

As year round minnow flow requirements increase from 0 to 50 to 100 cfs, New Mexico's M&I water use (Albuquerque) decreases by 0.29 percent, 0.38 percent, and 39.22 percent, respectively under the river's current operating rules. El Paso's M&I water use decreases by 0.63 percent, 0.50 percent, and 0.34 percent respectively under the same three flow requirement conditions. This moderation of drought losses faced by El Paso users occurs because increased upstream minnow flow requirements are met through reduced agricultural and M&I diversions. These reduced diversions leave more water available to flow downstream to Elephant Butte Reservoir,

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[9] In fact, a reduction by Albuquerque of this magnitude for the minnow is unlikely to ever occur because even after the City uses surface water exclusively, there is expected to be a backup groundwater pumping capacity that could be called upon for short term emergencies when surface flows are very low and when the minnow still needs 100 cfs year around.

3.2.2 Economic Impact

An important research challenge in the Rio Grande Basin is to understand and predict the economic consequences of policies that provide or alter instream flow deliveries for endangered species. This section focuses on the economic impacts of providing water to support minimum instream flows for habitat requirements for the endangered Rio Grande Silvery Minnow. Those impacts are described, both as they affect agricultural and M&I water users.

3.2.2.1 Agriculture

Table 12 shows the change in the average annual economic benefits that would occur if minnow flows scenarios are provided. The second column represents the percentage on the economic benefits generated by the water users, under the selected minimum minnow flows requirement, on each agricultural water user of the three states.

These results are produced by the policy of establishing the minnow's flow scenarios compared to the baseline where there are no guaranteed minnow flows. Colorado agriculture in the San Luis Valley suffers no economic losses from New Mexico's minnow flows for the same reason that it suffers no loss in water use: Colorado's Rio Grande Compact delivery requirements do not depend on New Mexico's endangered species critical habitat needs. The loss shown in the table is only a result of the drought's impacts on the Colorado agriculture economic benefits generated as a fact of reduced water use.

In New Mexico and Texas, agricultural water users show a negative response to the minnow flow requirements at San Acacia Gauge. New Mexico agriculture loses respectively about $16.7 million and $16.1 million in net income when providing 50 and 100 cfs daily flows for the endangered silvery minnow. This means that agriculture sees a decline of 48 to 50 percent of its normal annual net income generated in wet years even with no flow requirements for the silvery minnow.

3.2.2.2 M&I

Table 13 presents the economic impact of providing various levels of minimum streamflow to support habitat for the silvery minnow. Water users in both Albuquerque and El Paso typically incur comparatively small costs from providing the minnow flows. 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. We estimate this very high loss of $99.1 million in Albuquerque's economic benefit from reduced M&I 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 percent from about 307,000 acre feet to zero acre feet per year. 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.

After New Mexico has eliminated agricultural use on behalf of the minnow, the only remaining reductions will come from reduced M&I 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 with no minnow flow requirement.[10] When this set of conditions occurs, the incremental value of water is considerably higher for M&I uses than for agriculture. This condition is shown to occur at all points above and to the left of the kink point on the aggregate market (outer) demand curve for water in Figure 3.

3.2.2.3 Both Sectors

The silvery minnow flows scenarios also have an impact on the price (marginal value) of water on each sector of the Rio Grande watershed. Table 14 shows the impact on water's price that would occur when drought conditions occur combined with various minimum instream flow requirements for the minnow.

The results show similar results as seen in Table 9, which showed the effect on water's price of a decrease in surface water supply. The current table shows the effect on water's price associated with the most extreme drought condition combined with three possible instream flow requirements for the minnow. In much the same way as table 9, the price of water in the current table is interpreted as the incremental (marginal) benefit of its use by any sector at any point in the basin.

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[10] In fact, a reduction by Albuquerque of this magnitude for the minnow is unlikely to ever occur because even after the City uses surface water exclusively, there is likely to remain a backup groundwater pumping capacity available for short term emergencies when surface flows are very low and when the minnow still needs 100 cfs year around.

Results show that as the river's basin inflows decrease, the price of water increases for all users, even when there are no minimum flow requirements for the minnow. However, even under severe drought conditions, 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 (Rio Grande 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.

When comparing incremental values of water from one state to the next, these prices are highly unequal under any minimum streamflow scenario. For example Table 14 shows that New Mexico typically has the lowest incremental economic value of water in any water supply situation. This occurs because of comparatively 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 active and productive agriculture.[11]

The table shows that under the baseline full flow conditions, the marginal value of an additional acre foot is about $10 for all New Mexico users above Elephant Butte Reservoir, while it is about $25 for all users below the reservoir. As was the case for table 9, these prices indicate incremental values gained or lost if one more acre foot could be provided or if one more acre foot were lost to any given user.

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[11] However, Colorado agriculture, despite its much higher marginal value than either Texas or New Mexico agriculture, has a considerably lower value than does either New Mexico or Texas M&I uses.

The table also shows that as regional supplies are progressively altered due to instream flow requirements inside New Mexico above Elephant Butte Reservoir, the price of water (marginal value) always stays equal among competing users within each state, but all marginal values change as the instream flow requirements change.

Thus under severe drought conditions, when there are no instream flow requirements the marginal value of one additional acre foot increases to about $225 in Colorado and increases to just under $50 in New Mexico above Elephant Butte, and rises to about $85 for all users below the reservoir. As instream flow requirements increase from zero to 50 cfs and then to 100 cfs, marginal values in Colorado are unchanged because the combination of the Compact and the instream flow requirements have no effect on use inside Colorado. However for all New Mexico use above Elephant Butte, the marginal value increases with greater instream flow requirements because water diversions must be accordingly reduced by both agriculture and M&I users. However, water's price below Texas falls in the face of the higher flow requirements because those requirements produce additional amounts of water in Elephant Butte, which is all available for beneficial use downstream of the reservoir.

Finally, at the highest instream flow requirement under severe drought, the price of water rises to its maximum above Elephant Butte in agriculture at $67.00 per acre foot at which point there is zero use in agriculture in that part of New Mexico. The price of water for Albuquerque M&I rises to $5044 per acre foot, the price required to release sufficient flow for the minnow downstream.

3.3 Impacts of Drought and Endangered Species Protection

3.3.1 Hydrologic Impact

Tables 15 and 16 show the impact on water use in the basin resulting from a combination of five levels of drought and three levels of instream flow deliveries for endangered species protection. Table 15 shows absolute impacts on water use, while table 16 shows percentage changes compared to baseline use patterns.

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, the two tables show 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 M&I water use are generally small until the most severe drought is combined with the largest minnow flow deliveries are required.

3.3.1.1 Agriculture

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 42.0 thousand acre feet reduced use under mild drought conditions to 265.1 thousand acre feet reduced use under a severe drought falling to 50 percent of normal basin inflows. The other three irrigated areas also incur greater water use reductions in the face of droughts of greater severity.

Second, the impact of instream flow deliveries for endangered species habitat is distributed rather differently among the four irrigation areas: Without additional state or federal legislation, water use by Colorado agriculture is not influenced at all by the instream flow delivery requirements for the minnow. By contrast water use by New Mexico agriculture above Elephant Butte Reservoir (NM_1) is reduced strongly by instream 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 15 shows that central New Mexico agriculture's water use falls by about 206 thousand acre feet when there is no instream flow requirement downstream. However, it falls by 100 percent of its use from 307 thousand acre feet to zero when 100 cfs of instream 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 less loss in use as instream flow requirements are increased, particularly when basin inflows are the lowest. For example, both of these regions are seen to suffer much smaller drought losses in water use as instream flow delivery requirements are higher when inflows are at 50 percent of the long run average.

3.3.1.2 M&I

Tables 15 and 16 shows respectively the absolute change and the percentage change of the water consumptive uses in the Rio Grande basin due to the impact of drought and silvery minnow flows scenarios. Results shown in both tables show that the silvery minnow flow requirements and drought have comparatively minor effects on M&I water use, with total M&I use almost always being reduced by less than 1000 acre feet compared to normal flow conditions without minnow flow protection.

Only in the driest flow periods considered (50 percent of the total normal water supply) combined with the highest instream flow delivery requirements will M&I users face appreciable reductions in water use. And even then, only New Mexico M&I users are the ones who incur major water use reductions. This major use reduction occurs under the driest conditions combined with the highest instream flow requirements because there is no more water to be had from further reductions in agricultural use. All further reductions must come from reduced M&I uses.

3.3.2 Economic Impact

Table 17 and Table 18 show the loss in average annual economic benefits that would occur to both agriculture and to M&I water use under 15 water supply scenarios. These scenarios include all combinations of five levels of drought and three levels of instream flow protection. Included in the two tables are impacts to each sector and total impacts summed over both sectors split out separately for each of the three states. Table 17 presents absolute economic damages, while table 18 presents percentage changes compared to baseline conditions.

3.3.2.1 Agriculture

As was the case for hydrological impacts described by tables 15 and 16, 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 percent 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.

Second, the impact on agricultural net income resulting from instream flow deliveries for endangered species habitat is distributed quite differently among the four irrigation areas: Without additional state or federal legislation, net income in Colorado agriculture is not influenced at all by the instream 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 instream 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 17 shows that central New Mexico agriculture's net income falls by about $6.0 million when there is no instream flow requirement downstream. However, it falls by 100 percent of baseline level from $9.85 million to zero use when 100 cfs of instream 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 economic losses as instream 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 instream flow delivery requirements are higher when inflows are at 50 percent of the long run average. New Mexico agriculture below Elephant Butte Reservoir (NM_2) loses about $10 million under the most severe drought without upstream instream flow delivery requirements. However when upstream appropriators must supply instream flows that end up in Elephant Butte Reservoir, those agricultural losses fall to about $4.2 million. Similar results occur for west Texas agriculture.

3.3.2.2 M&I

Economic damages to the basin's M&I users under the 15 water supply scenarios follow a similar pattern as was produced by hydrological damages described in tables 15 and 16 resulting from water use reductions. Tables 17 and 18 show that economically, water users in both Albuquerque and El Paso typically incur comparatively small costs from reacting to drought as well as from policies requiring instream flow protection for the silvery minnow.

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 percent of long run average. As stated previously, this very high loss of $99.1 million in Albuquerque's ratepayers' economic benefit from reduced M&I 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 percent 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.

After New Mexico has eliminated agricultural use on behalf of the minnow, the only remaining reductions will come from reduced M&I 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 M&I uses than for agriculture. For the remaining 14 combinations of future water supply scenarios, total economic cost to M&I 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 for M&I uses is considerably lower for M&I uses as for agricultural uses, so a small reduction in M&I use produces an equal economic loss as a large reduction in agricultural use.

3.3.2.3 Both Sectors

Table 19 shows the impact of the above-described 15 water supply scenarios on the price of water. As stated previously, water's price is interpreted as the marginal value of an additional acre foot supplies at each point of use described in the table. Results shown in table 19 are approximately equal to the ratio of economic effects in table 17 to hydrological impacts in table 15. For example, table 19 shows that the price of water for New Mexico agriculture above Elephant Butte (NM1) is $48.39 under a 50 percent supply scenario and zero instream flow requirement. Table 17 shows that NM1 suffers a $6.04 million net income loss from a 206 thousand acre foot reduction in use shown in Table 15. Note that the price of water for that cell, $48.39 is approximately equal to the ratio of lost income to lost water [$6.04 million / 206 thousand = $30]. The difference between the exact price, $48.39 and its approximation of dincome / d water = $30 comes from the fact that $30 is the correct shadow price for the non-marginal change in water use equal to 206,000 acre feet. If the water supply change is only 1 acre foot, the marginal income lost is $48.39, the price shown in table 19.

Table 19 table shows the effect on water's price associated with all five drought condition combined with three possible instream flow requirements for the minnow. In much the same way as table 14, the price of water in table 19 is interpreted as the incremental (marginal) benefit of its use by any sector at any point in the basin.

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).

Table 19 shows that under the baseline full flow conditions, the marginal value of an additional acre foot is about $10 for all New Mexico users above Elephant Butte Reservoir, while it is about $25 for all users below the reservoir. As was the case for table 14, these prices indicate incremental values gained or lost if one more acre foot could be provided or if one more acre foot were lost to any given user.

The table also shows that as regional supplies are progressively altered due to instream flow requirements inside New Mexico above Elephant Butte Reservoir, the price of water (marginal value) always stays equal among competing users within each state, but all marginal values change as the instream flow requirements change.

One very interesting result of the table 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 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 taken out of 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 accessible use, water's price can change considerably.

4 Conclusions

The potential of occurrence of drought and the associated adverse consequences for the economy, political systems, and social institutions has always been an issue in the Rio Grande watershed. In addition, the U.S. Endangered Species Act and its amendments that emphasize the protection of endangered species with limited consideration of cost, have furthered an increase competition in the basin for already scarce water. In light of the considerable economic importance of water throughout the western U.S., it is important to have information on the economic costs of saving species so that people who are called upon to pay the money or water needed can contribute to informed choices for measures to save the species consistent with biological requirements.

The objective of this study was to evaluate and identify the economic and hydrologic impacts to the Rio Grande water users where 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 instream flows scenarios to protect the silvery minnow. The model also responds to relative water scarcity as those scarcities are reflected through various institutions governing the allocation of the basin's water.

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 M&I 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 percent above Elephant Butte Reservoir and by 43 percent below the reservoir when surface water flows are reduced by 50 percent 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 percent of its net income compared to that earned in a normal runoff year.

Protecting instream flows for the silvery minnow during dry years produces economic losses for both agriculture and M&I uses of water in the Rio Grande watershed. The instream flows scenarios increase the economic losses that water users above Elephant Butte Reservoir in New Mexico experience during drought years. Instream flow requirements have the largest impacts on agricultural water users in New Mexico and Texas. Hydrologic and economic impacts are more pronounced when instream flow requirements dictate larger quantities of water be reserved for endangered species habitat.

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6 Tables

6.1 Table 1: Irrigated Area in the United States, by Region, 2002

Table 1: Irrigated Area in the United States, by Region, 2002 (USDA Census of Agriculture)

Region	Harvested Cropland Irrigated	Pastureland Irrigated	Total Irrigated Area
	million acres		
United States	50.0	5.0	55.0
West (1)	38.2	4.8	43.0
East	11.8	0.2	12.0

(1) West includes HI, AK, WA, OR, CA, ID, NV, MT, WY, UT, CO, AZ, NM, ND, SD, NE, KS, OK, and TX.

6.2 Table 2: Irrigated Areas in the United States, by Region, 2002

Table 2: Irrigated Areas in the United States, by Region, 2002 (USDA Economic Research Service, p. 8).

Region	Sector	Water Withdrawals	Consumptive Water Use
		Million acre-feet	
United States	All	382	112
	Irrigation	150	91
West (1)	All	179	88
	Irrigation	133	79
East	All	203	24
	Irrigation	17	12

(1) West includes HI, AK, WA, OR, CA, ID, NV, MT, WY, UT, CO, AZ, NM, ND, SD, NE, KS, OK, and TX.

6.3 Table 3: Summary Agricultural Statistics, Rio Grande Basin, Colorado, New Mexico, and Texas

Table 3: Summary Agricultural Statistics, Rio Grande Basin, Colorado, New Mexico, and Texas [12]

	Colorado Rio Grande Water Conservation District Rio Grande, Alamosa, Conejos, and Costilla Counties	New Mexico Middle Rio Grande Conservancy District Sandoval, Bernallilo, Valencia, and Socorro Counties	New Mexico Elephant Butte Irrigation District Sierra and Dona Ana Counties	Texas El Paso County Water Improvement District #1 El Paso County
Irrigated Land				
Farms	844	1,487	1,716	474
Acres	277,284	45,004	89,328	37,197
Farms by Value of Sales				
less than < $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

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[12] Data source: 2002 Census of Agriculture, County Data. Tables 1 and 10. URL is http://www.nass.usda.gov/census/census02/volume1/index2.htm

6.4 Table 4: Consumptive Uses by Location in the Rio Grande Basin

Table 4: Consumptive Uses by Location in the Rio Grande Basin						
	Surface Diversion	Ground Water Pumping	Crop Use	M&I Use	Surface Returns	Aquifer Returns
Southern Colorado Agriculture	+	+	+	-	+	+
Albuquerque M&I	-	+	-	+	+	-
MRGCD Agriculture	+	-	+	-	+	+
EBID Agriculture	+	+	+	-	+	+
El Paso M&I	+	+	-	+	+	+
El Paso Agriculture	+	-	+	-	+	+
Source: Ward et al., 2002						

6.5 Table 5: Hydrological Impacts of Drought on Agricultural Water Use, Rio Grande Basin, Without Streamflow Protection for Silvery Minnow

Table 5: Hydrological Impacts of Drought on Agricultural Water Use, Rio Grande Basin, Without Streamflow Protection for Silvery Minnow

Drought Scenarios	Total Water Use** (1000 acre-feet)				% Change from Baseline in Water Use			
	CO	NM_1	NM_2	TX	CO	NM_1	NM_2	TX
Baseline*	678.17	306.89	220.79	136.52	0.0	0.0	0.0	0.0
50% of normal***	-265.1	-206.5	-189.7	-119.3	-39.1	-67.3	-85.9	-87.4
60% of normal***	-201.0	-165.5	-158.4	-99.6	-29.6	-53.9	-71.7	-73.0
70% of normal***	-142.5	-124.1	-123.9	-77.9	-21.0	-40.4	-56.1	-57.1
80% of normal***	-89.5	-82.5	-86.1	-54.2	-13.2	-26.9	-39.0	-39.7
90% of normal***	-42.0	-41.0	-44.9	-28.3	-6.2	-13.4	-20.3	-20.7

* 100% of normal. This row reports the absolute level of water supply from which the percentage change or absolute difference is calculated.

** Water use based on each state's allocation under the Rio Grande Compact.

*** Figures report absolute differences and percentage changes from the baseline row.

6.6 Table 6: Hydrological Impacts of Drought on M&I Water Use, Rio Grande Basin, Without Streamflow Protection for Silvery Minnow

Table 6: Hydrological Impacts of Drought on M&I Water Use, Rio Grande Basin, Without Streamflow Protection for Silvery Minnow				
Drought Scenarios	Total Water Use** (1000 acre-feet)		% Change from Baseline in Water Use	
	NM	TX	NM	TX
Baseline*	84.39	75.72	0.0	0.0
50% of normal***	-0.29	-0.48	-0.3	-0.6
60% of normal***	-0.23	-0.40	-0.3	-0.5
70% of normal***	-0.17	-0.31	-0.2	-0.4
80% of normal***	-0.11	-0.21	-0.1	-0.3
90% of normal***	-0.05	-0.11	-0.1	-0.1

* 100% of normal. This row reports the absolute level of water supply from which the percentage change or absolute difference is calculated.

** Water use based on each State's allocation under the Rio Grande Compact.

*** Figures report absolute differences and percentage changes from the baseline row.

6.7 Table 7: Economic Impacts of Drought on Agricultural Benefits, Without Streamflow Protection for the Silvery Minnow

Table 7: Economic Impacts of Drought on Agricultural Benefits, Without Streamflow Protection for the Silvery Minnow

Drought Scenarios	Change in Economic Benefits (million $)				% Change from Baseline in Economic Benefit			
	CO	NM_1	NM_2	TX	CO	NM_1	NM_2	TX
Baseline*	157,870	9,856	23,927	8,003	0.0	0.0	0.0	0.0
50% of normal**	-56,430	-6,041	-10,295	-6,477	-35.7	-61.3	-43.0	-80.9
60% of normal**	-42,173	-4,212	-7,808	-4,912	-26.7	-42.7	-32.6	-61.4
70% of normal**	-29,491	-2,680	-5,434	-3,418	-18.7	-27.2	-22.7	-42.7
80% of normal**	-18,290	-1,463	-3,264	-2,053	-11.6	-14.9	-13.6	-25.7
90% of normal**	-8,485	-569	-1,409	-886	-5.4	-5.8	-5.9	-11.1

* 100% of normal. This row reports the total economic benefit, from which the percentage change or absolute difference is calculated. Positive values indicate gains, and negative values indicate losses from the baseline.

** Figures report absolute differences and percentage changes from the baseline row.

6.8 Table 8: Economic Impacts of Drought on M&I Benefits, Without Streamflow Protection for the Silvery Minnow

Table 8: Economic Impacts of Drought on M&I Benefits, Without Streamflow Protection for the Silvery Minnow

Drought Scenarios	Change in Economic Impacts (million $)		% Change in Economic Benefit	
	NM	TX	NM	TX
Baseline*	457,971	360,875	0	0
50% of normal**	-8.7	-26.1	-0.0019	-0.0072
60% of normal**	-6.1	-19.8	-0.0013	-0.0055
70% of normal**	-3.9	-13.8	-0.0009	-0.0038
80% of normal**	-2.1	-8.3	-0.0005	-0.0023
90% of normal**	-0.8	-3.6	-0.0002	-0.0010

* 100% of normal. This row reports the total economic benefit, from which the percentage change or absolute difference is calculated. Positive values indicate gains, and negative values indicate losses from the baseline.

** Figures report absolute differences and percentage changes from the baseline row.

6.9 Table 9: Impacts of Drought on Water Price, Without Streamflow Protection for the Silvery Minnow

Table 9: Impacts of Drought on Water Price, Without Streamflow Protection for the Silvery Minnow

Drought Scenarios	Price ($/af) Agriculture				Price ($/af) M&I	
	CO	NM_1	NM_2	TX	NM	TX
Baseline*	200.08	10.15	24.24	24.24	10.15	24.24
50% of normal**	225.65	48.39	84.33	84.33	48.39	84.33
60% of normal**	219.47	40.79	74.40	74.40	40.79	74.40
70% of normal**	213.83	33.11	63.49	63.49	33.11	63.49
80% of normal**	208.71	25.40	51.54	51.54	25.40	51.54
90% of normal**	204.13	17.73	38.47	38.47	17.73	38.47

*100% of normal. This row reports the price of water at the absolute level of water supply from which the percentage change or absolute difference is calculated.

**Figures report absolute water prices under the total supply for the row.

6.10 Table 10: Hydrological Impact on Agricultural Water Use of Selected Instream Flow Protection Scenarios for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Table 10: Hydrological Impact on Agricultural Water Use of Selected Instream Flow Protection Scenarios for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Minimum Year-Round Flows for Silvery Minnow (cfs)	Total Water Use (1000 acre-feet)				% Change from Baseline In Water Use			
	CO	NM_1	NM_2	TX	CO	NM_1	NM_2	TX
Baseline**	678.10	306.89	220.79	136.50	0	0	0	0
0	-265.10	-206.52	-189.65	-119.31	-39.1	-67.3	-85.9	-87.4
50	-265.10	-268.83	-151.40	-95.25	-39.1	-87.6	-68.6	-69.8
100	-265.10	-306.89	-104.21	-65.56	-39.1	-100.0	-47.2	-48.0

* The drought scenario of 50% of normal water entering the basin with the three alternative minimum year round instream flow protection levels indicated in the table.

**Baseline refers to 100% of normal inflow to the basin, 1.57 million acre-feet per year

6.11 Table 11: Hydrological Impact on M&I Water Use of Selected Instream Flow Protection for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Table 11: Hydrological Impact on M&I Water Use of Selected Instream Flow Protection Scenarios for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Minimum Year-Round Flows for Silvery Minnow (cfs)	Total Water Use (1000 acre-feet)		% Change from Baseline in Water Use	
	NM	TX	NM	TX
Baseline**	84.39	75.72	0	0
0	-0.29	-0.48	-0.34	-0.63
50	-0.38	-0.38	-0.45	-0.50
100	-39.22	-0.26	-46.47	-0.34

*The drought scenario of 50% of normal water entering the basin with the three alternative minimum year round instream flow protection levels indicated in the table.

**Baseline refers to 100% of normal inflow to the basin, 1.57 million acre-feet per year.

6.12 Table 12: Economic Impacts on Agricultural Benefits of Selected Instream Flow Protection Scenarios for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Table 12: Economic Impacts on Agricultural Benefits of Selected Instream Flow Protection Scenarios for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Minimum Year-Round Flows for Silvery Minnow (cfs)	Change in Economic Benefit (million $)				% Change in Economic Benefit			
	CO	NM$_1$	NM$_2$	TX	CO	NM$_1$	NM$_2$	TX
Baseline**	157,870	9,856	23,927	8,003	0	0	0	0
0	-56,430	-6,040	-10,295	-6,477	-35.7	-61.3	-43.0	-80.9
50	-56,430	-9,415	-7,302	-4,594	-35.7	-95.5	-30.5	-57.4
100	-56,430	-9,856	-4,247	-2,672	-35.7	-100.0	-17.8	-33.4

* The drought scenario of 50% of normal water entering the basin with the three alternative minimum year round instream flow protection levels indicated in the table..

**Baseline refers to 100% of normal inflow to the basin, 1.57 million acre-feet per year

6.13 Table 13: Economic Impacts on M&I Benefits of Selected Instream Flow Protection Scenarios for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Table 13: Economic Impacts on M&I Benefits of Selected Instream Flow Protection Scenarios for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Minimum Year-Round Flows for Silvery Minnow (cfs)	Change in Economic Benefit (million $)		% Change in Economic Benefit	
	NM	TX	NM	TX
Baseline**	457,972	360,875	0	0
0	-8.72	-26.05	-0.002	-0.007
50	-13.59	-18.48	-0.003	-0.005
100	-99,130	-10.75	-21.64	-0.003

* The drought scenario of 50% of normal water entering the basin with the three alternative minimum year round instream flow protection levels indicated in the table.

**Baseline refers to 100% of normal inflow to the basin, 1.57 million acre-feet per year

6.14 Table 14: Impacts on Water Price for all Water Users of Selected Instream Flow Protection Scenarios for Silvery Minnow, Rio Grande Basin, 50% of Normal Water Supply*

Table 14: Impacts of Selected Instream Flow Protection Scenarios for Silvery Minnow on Water Price, Rio Grande Basin, 50% of Normal Water Supply*

Minimum Year-Round Flows for Silvery Minnow (cfs)	Price ($/af) Agriculture				Price ($/af) M&I	
	CO	NM$_1$	NM$_2$	TX	NM	TX
Baseline**	200.08	10.15	24.24	24.24	10.15	24.24
0	225.65	48.39	48.39	84.33	48.39	84.33
50	225.65	59.93	72.21	72.21	59.93	72.21
100	225.65	67.00	57.26	57.26	5044.39	57.26

* 50% of normal. This row reports the drought scenario of 50% of normal water supply at different instream flow protection scenarios for Silvery Minnow and from which the percentage change or absolute difference is calculated.

**Baseline refers to 100% of normal inflow to the basin, 1.57 million acre-feet per year

6.15 Table 15: Impacts of Drought and Endangered Species Protection on Water Use in the Rio Grande River Basin (Absolute Levels of Water Use)

Table 15**:** Impacts of Drought and Endangered Species Protection on Water Use in the Rio Grande River Basin (Absolute Levels of Water Use)

Drought & 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 M&I (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	-265.10	-420.61	-95.63	-265.10	-268.83	-151.40	-95.25	-0.38	-0.38
	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
	50	-201.00	-328.42	-95.63	-201.00	-176.77	-151.40	-95.25	-0.25	-0.38
	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
	50	-142.50	-248.10	-78.21	-142.50	-124.06	-123.87	-77.90	-0.17	-0.31
	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
	50	-89.50	-168.70	-54.41	-89.50	-82.45	-86.14	-54.20	-0.11	-0.21
	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
	50	-42.00	-85.99	-28.41	-42.00	-41.02	-44.92	-28.30	-0.05	-0.11
	100	-42.00	-85.99	-28.41	-42.00	-41.02	-44.92	-28.30	-0.05	-0.11

*The top row contains zero absolute change in baseline water supply conditions. Zero Silvery Minnow flow means no instream flow protection for the endangered Rio Grande Silvery Minnow.

6.16 Table 16: Impacts of Drought and Endangered Species Protection on Water Use in the Rio Grande River Basin (Percentage Change)

Table 16: Impacts of Drought and Endangered Species Protection on Water Use in the Rio Grande River Basin (Percentage Change)

Drought & Minimum Flow Scenarios		% Change in Water Use All Sectors			% Change in Water use Agriculture				% Change in Water Use M&I	
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	-39.1	-58.5	-56.4	-39.1	-67.3	-85.9	-87.4	-0.3	-0.6
	50	-39.1	-62.0	-45.0	-39.1	-87.6	-68.6	-69.8	-0.5	-0.5
	100	-39.1	-66.4	-31.0	-39.1	-100.0	-47.2	-48.0	-46.5	-0.3
60%	0	-29.6	-47.8	-47.1	-29.6	-53.9	-71.7	-73.0	-0.3	-0.5
	50	-29.6	-48.4	-45.0	-29.6	-57.6	-68.6	-69.8	-0.3	-0.5
	100	-29.6	-52.8	-31.0	-29.6	-82.6	-47.2	-48.0	-0.4	-0.3
70%	0	-21.0	-36.6	-36.8	-21.0	-40.4	-56.1	-57.1	-0.2	-0.4
	50	-21.0	-36.6	-36.8	-21.0	-40.4	-56.1	-57.1	-0.2	-0.4
	100	-21.0	-38.4	-31.0	-21.0	-50.8	-47.2	-48.1	-0.3	-0.3
80%	0	-13.2	-24.9	-25.6	-13.2	-26.9	-39.0	-39.7	-0.1	-0.3
	50	-13.2	-24.9	-25.6	-13.2	-26.9	-39.0	-39.7	-0.1	-0.3
	100	-13.2	-24.9	-25.6	-13.2	-26.9	-39.0	-39.7	-0.1	-0.3
90%	0	-6.2	-12.7	-13.4	-6.2	-13.4	-20.3	-20.7	-0.1	-0.1
	50	-6.2	-12.7	-13.4	-6.2	-13.4	-20.3	-20.7	-0.1	-0.1
	100	-6.2	-12.7	-13.4	-6.2	-13.4	-20.3	-20.7	-0.1	-0.1

*The top row contains zero percentage change in baseline water supply conditions. Zero Silvery Minnow flow means no instream flow protection for the endangered Rio Grande Silvery Minnow.

6.17 Table 17: Impacts of Drought and Endangered Species Protection on Economic Benefit in the Rio Grande Basin

Table 17: Impacts of Drought and Endangered Species Protection on Economic Benefit in the Rio Grande Basin

Drought & Minimum Flow Scenarios		Change in Economic Benefits All Sectors ($1000 / yr)			Change in Economic Benefits Agriculture ($1000 / yr)				Change in Economic Benefits M&I ($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	-56,430	-16,731	-4,612	-56,430	-9,415	-7,302	-4,594	-14	-18
	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
	50	-42,173	-11,992	-4,613	-42,173	-4,683	-7,302	-4,594	-7	-19
	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
	50	-29,491	-8,119	-3,432	-29,491	-2,681	-5,434	-3,418	-4	-14
	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
	50	-18,290	-4,730	-2,061	-18,290	-1,464	-3,264	-2,053	-2	-8
	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
	50	-8,485	-1,980	-890	-8,485	-570	-1,409	-886	-1	-4
	100	-8,485	-1,980	-890	-8,485	-570	-1,409	-886	-1	-4

*The top row contains zero absolute change in the monetary value of economic benefits. Lower 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.

6.18 Table 18: Impacts of Drought and Endangered Species Protection on Economic Benefit in the Rio Grande Basin (Percentage Change)

Table 18: Impacts of Drought and Endangered Species Protection on Economic Benefit in the Rio Grande Basin (Percentage Change)

Drought & Minimum Flow Scenarios		% Change in Economic Benefits All Sectors			% Change in Economic Benefits Agriculture				% Change in Economic Benefits M&I	
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
50%	0	-35.7	-3.5	-1.8	-35.7	-61.3	-43.0	-80.9	-0.0020	-0.0072
	50	-35.7	-3.6	-1.3	-35.7	-95.5	-30.5	-57.4	-0.0031	-0.0050
	100	-35.7	-24.2	-0.7	-35.7	-100.0	-17.8	-33.4	-21.6456	-0.0030
60%	0	-26.7	-2.6	-1.3	-26.7	-42.7	-32.6	-61.4	-0.0013	-0.0055
	50	-26.7	-2.6	-1.3	-26.7	-47.5	-30.5	-57.4	-0.0015	-0.0051
	100	-26.7	-2.7	-0.7	-26.7	-86.5	-17.8	-33.4	-0.0027	-0.0030
70%	0	-18.7	-1.7	-0.9	-18.7	-27.2	-22.7	-42.7	-0.0009	-0.0038
	50	-18.7	-1.7	-0.9	-18.7	-27.2	-22.7	-42.7	-0.0009	-0.0038
	100	-18.7	-1.7	-0.7	-18.7	-38.9	-17.8	-33.4	-0.0012	-0.0030
80%	0	-11.6	-1.0	-0.6	-11.6	-14.9	-13.6	-25.7	-0.0005	-0.0023
	50	-11.6	-1.0	-0.6	-11.6	-14.9	-13.6	-25.7	-0.0005	-0.0023
	100	-11.6	-1.0	-0.6	-11.6	-14.9	-13.6	-25.7	-0.0005	-0.0023
90%	0	-5.4	-0.4	-0.2	-5.4	-5.8	-5.9	-11.1	-0.0002	-0.0010
	50	-5.4	-0.4	-0.2	-5.4	-5.8	-5.9	-11.1	-0.0002	-0.0010
	100	-5.4	-0.4	-0.2	-5.4	-5.8	-5.9	-11.1	-0.0002	-0.0010

*The top row contains zero percentage change in the monetary value of economic benefits. Lower rows contain percentage 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.

6.19 Table 19: Impacts of Drought and Endangered Species Protection on Water's Price in the Rio Grande Basin

Table 19: Impacts of Drought and Endangered Species Protection on Water's Price in the Rio Grande Basin

Drought & Minimum Flow Scenarios		Price ($/af) Agriculture				Price ($/af) M&I	
Drought Conditions	Silvery Minnow Flows cfs	CO	NM_1	NM_2	TX	NM	TX
Baseline*		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	225.65	59.93	72.21	72.21	59.93	59.93
	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
	50	219.47	42.87	72.21	72.21	42.87	72.21
	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
	50	213.83	33.11	63.49	63.49	33.11	63.49
	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
	50	208.71	25.40	51.54	51.54	25.40	51.54
	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
	50	204.13	17.73	38.47	38.47	17.73	38.47
	100	204.13	17.73	38.47	38.47	17.73	38.47

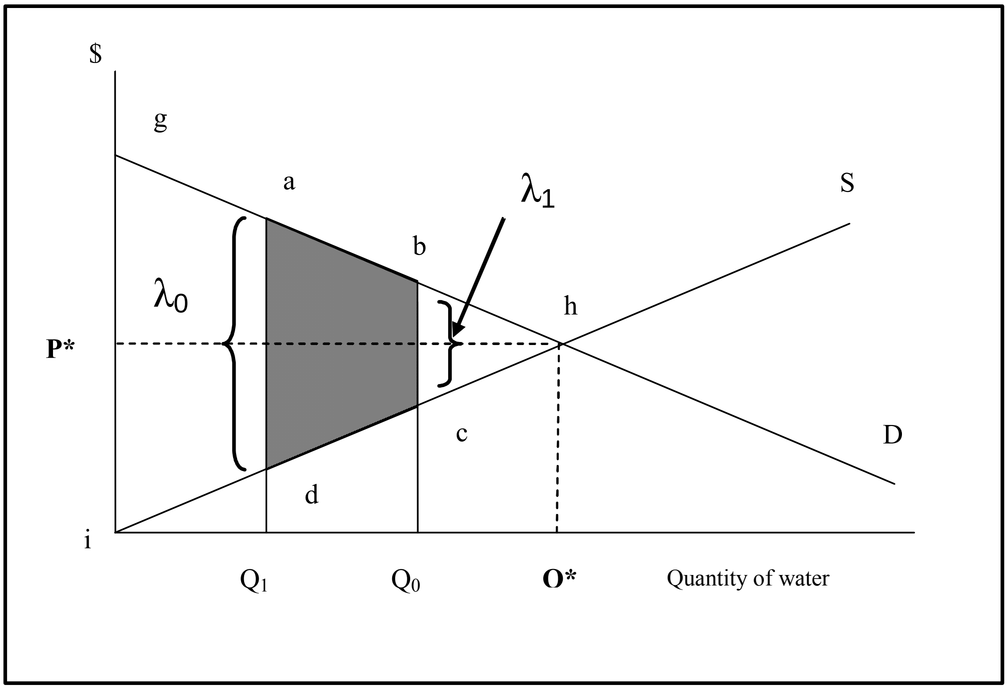
*100% of normal. This row reports the price of water under a full supply situation in which there are no flow requirements for the minnow. Price refers to the incremental economic benefits per additional acre foot.

**Figures report absolute water prices under the total supply defined by conditions for the row.

7 Figures

7.1 Figure 1: Rio Grande Basin above Ft. Quitman, Texas

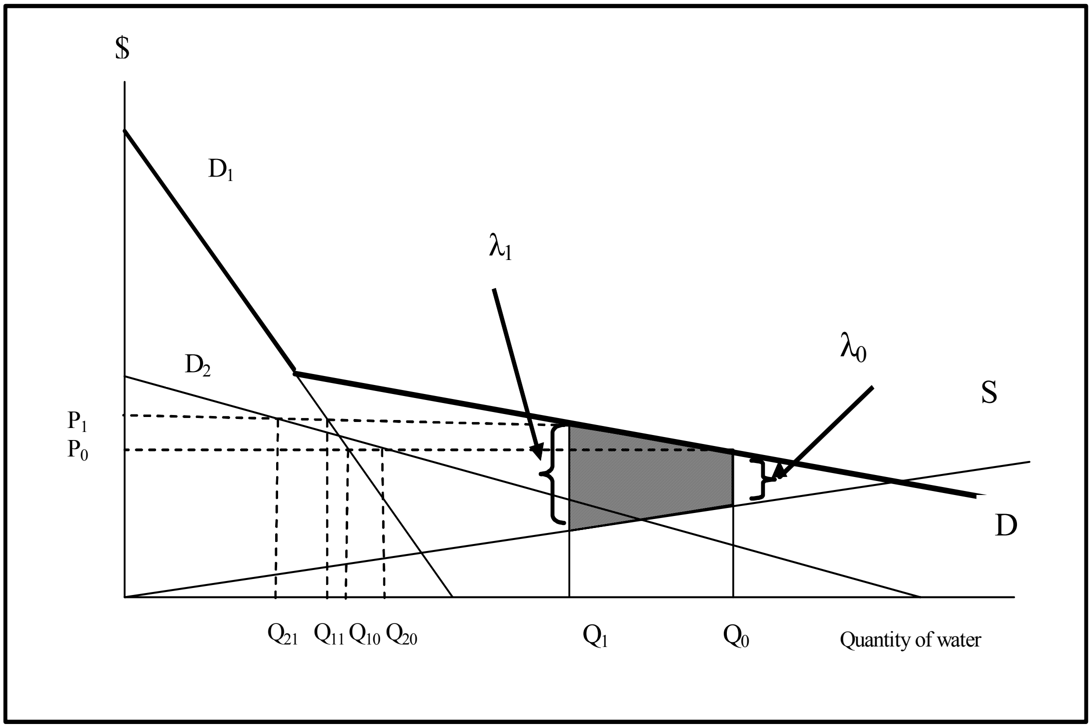
7.2 Figure 2: Efficient Water Use in a Single Water Market



LEGEND:

S: Supply schedule.
D: Demand Schedule.
λ_0 and **λ_1**: Shadow prices of water.
Q: Quantity of water.
P: Price of water.
Shaded area "**abcd**" is the additional consumer and producer surplus by increasing supply from Q_1 to Q_0.

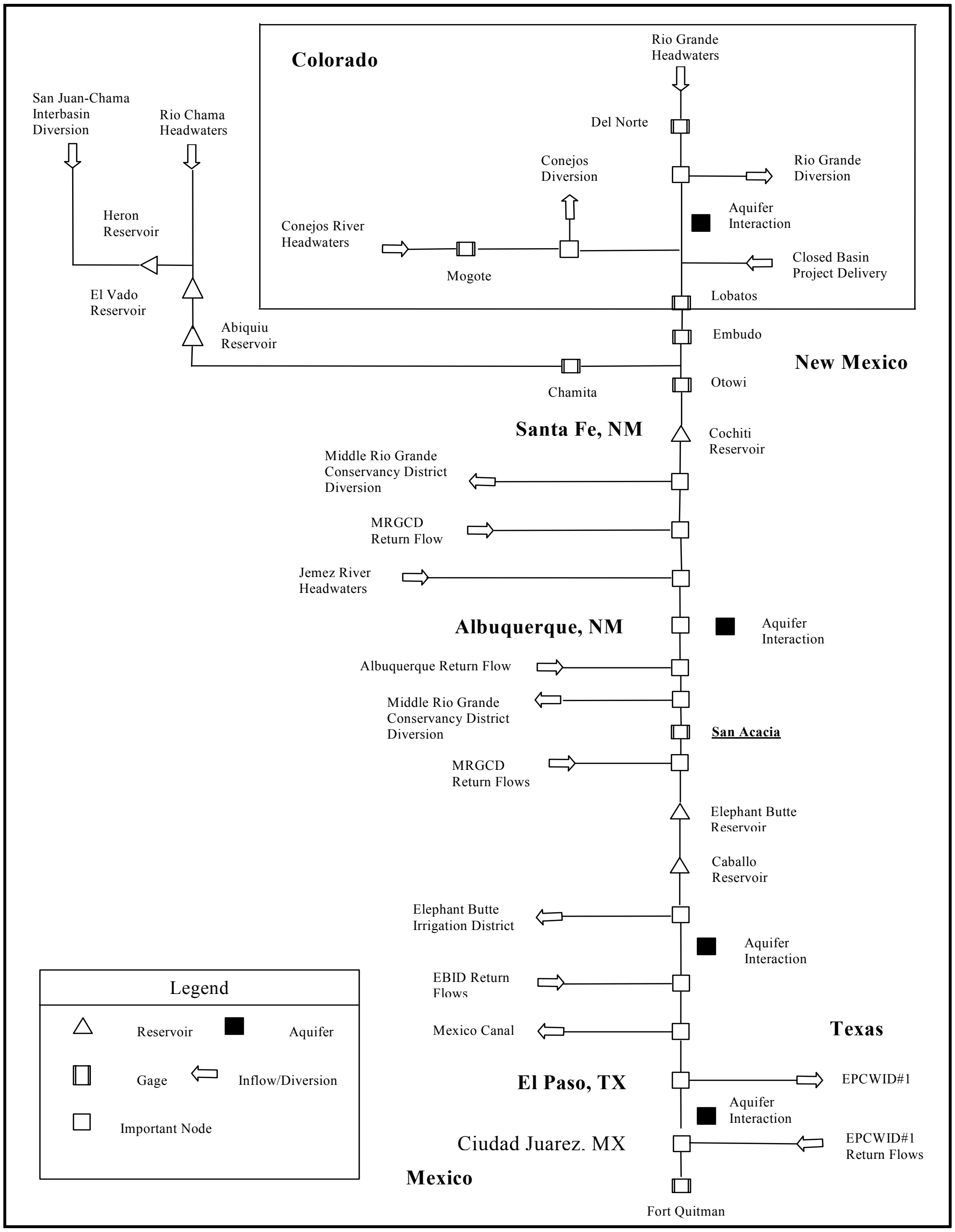
7.3 Figure 3: Efficient Water Allocation in Two Sector Market



LEGEND:

S: Supply schedule.
D$_1$: Demand schedule for sector 1.
D$_2$: Demand schedule for sector 2.
D: Total demand (horizontal summation of **D**$_1$ and **D**$_2$).
λ_1 and λ_2: Shadow prices of water.
Q: Quantity of water.
P: Price of water.
The shaded area is the change in the consumer and producer surplus resulting from a reduction in supply from Q_0 to Q_1.

7.4 Figure 4: Schematic of the Upper Rio Grande Basin[13]



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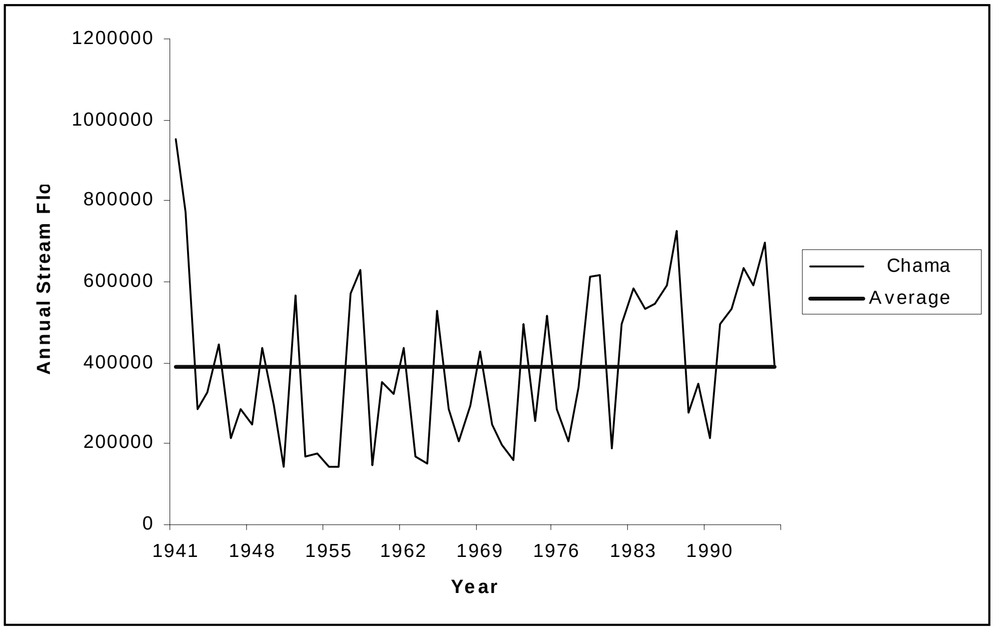
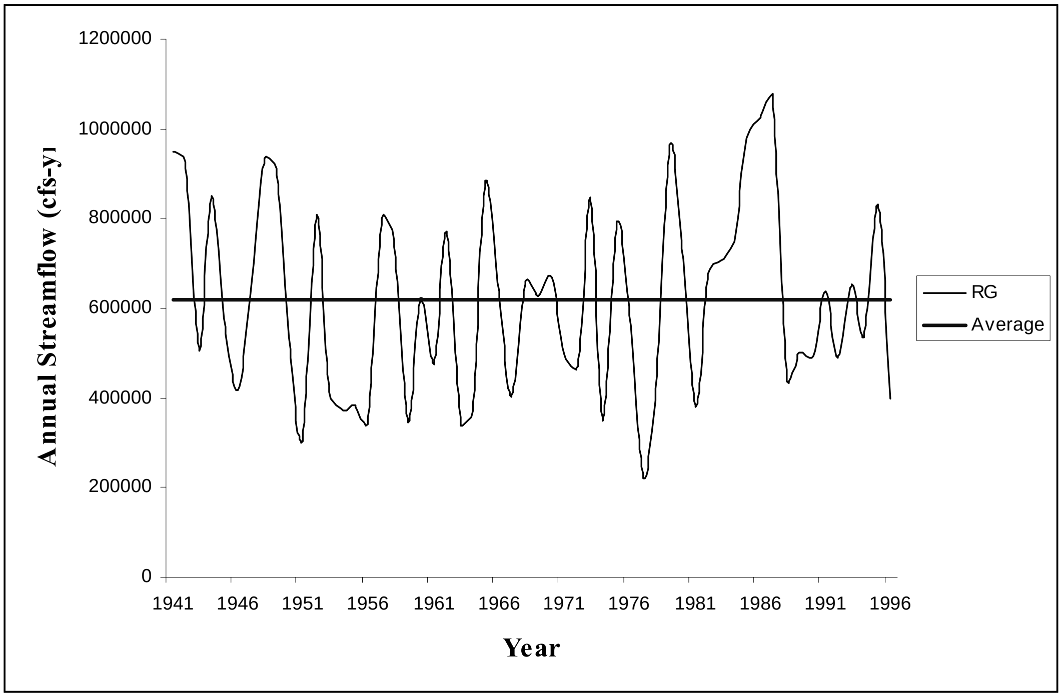
[13] The Upper Basin is defined in this report as those lands in Colorado, New Mexico, and Texas drained from the headwaters in southern Colorado to Fort Quitman, Texas (See Figure 1).

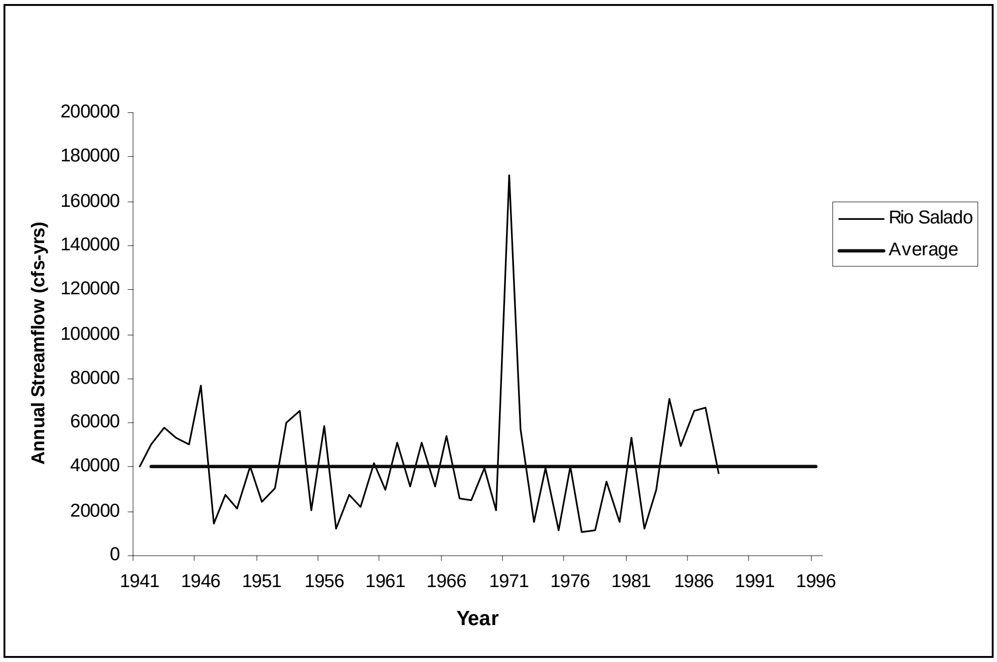
7.5 Figure 5: Rio Chama Headwater Gage Annual Streamflow



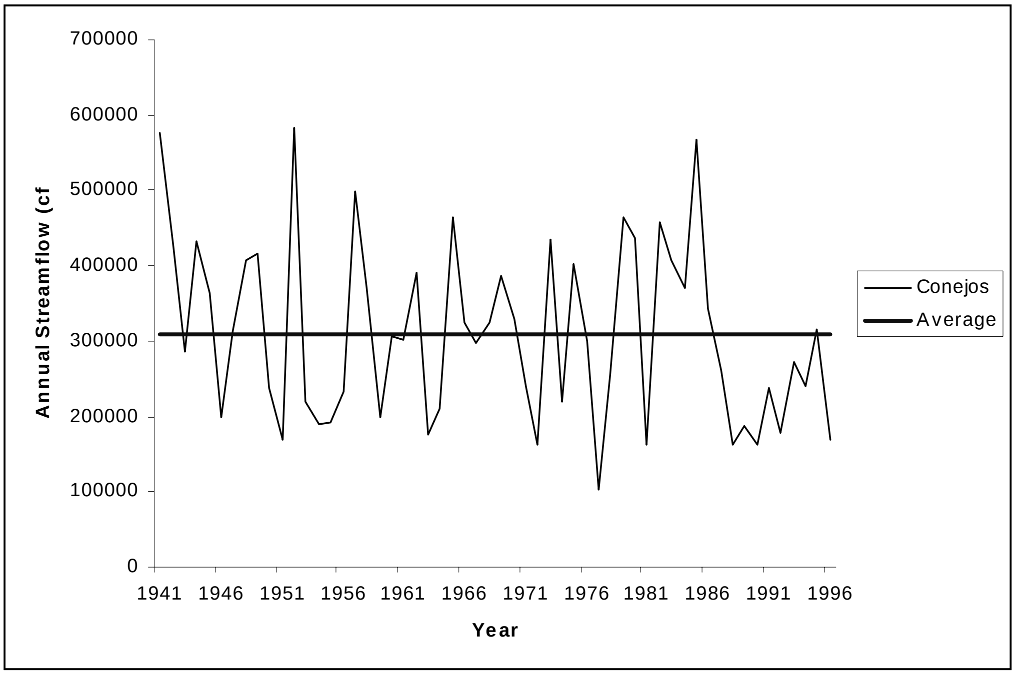
7.6 Figure 6: Rio Grande Headwater Gage Annual Streamflow



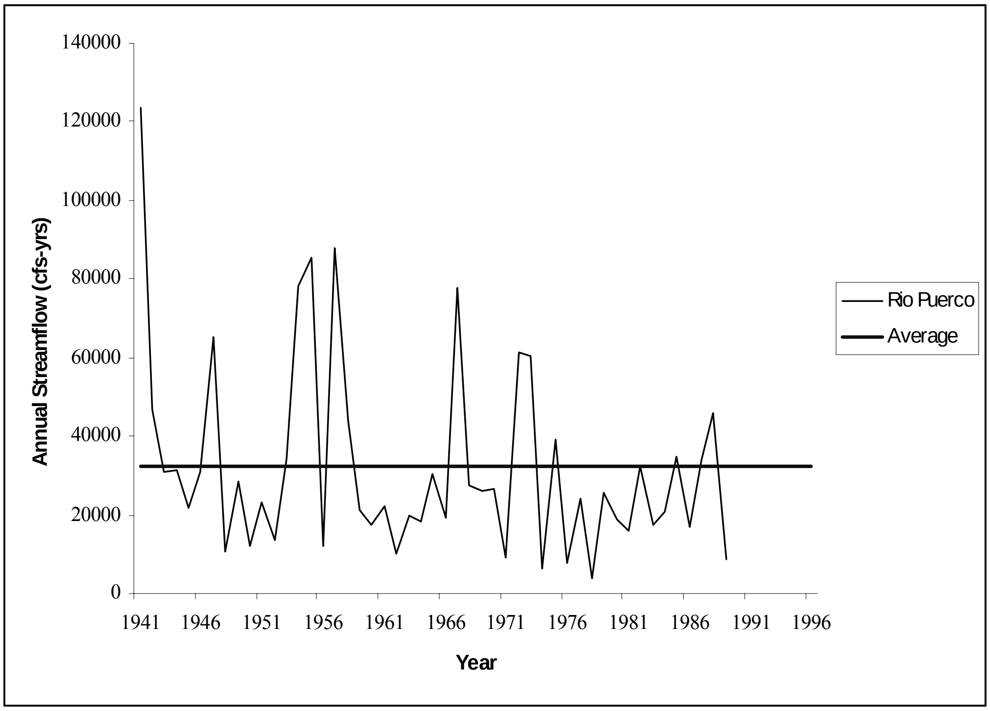
7.7 Figure 7: Rio Salado Headwater Gage Annual Streamflow



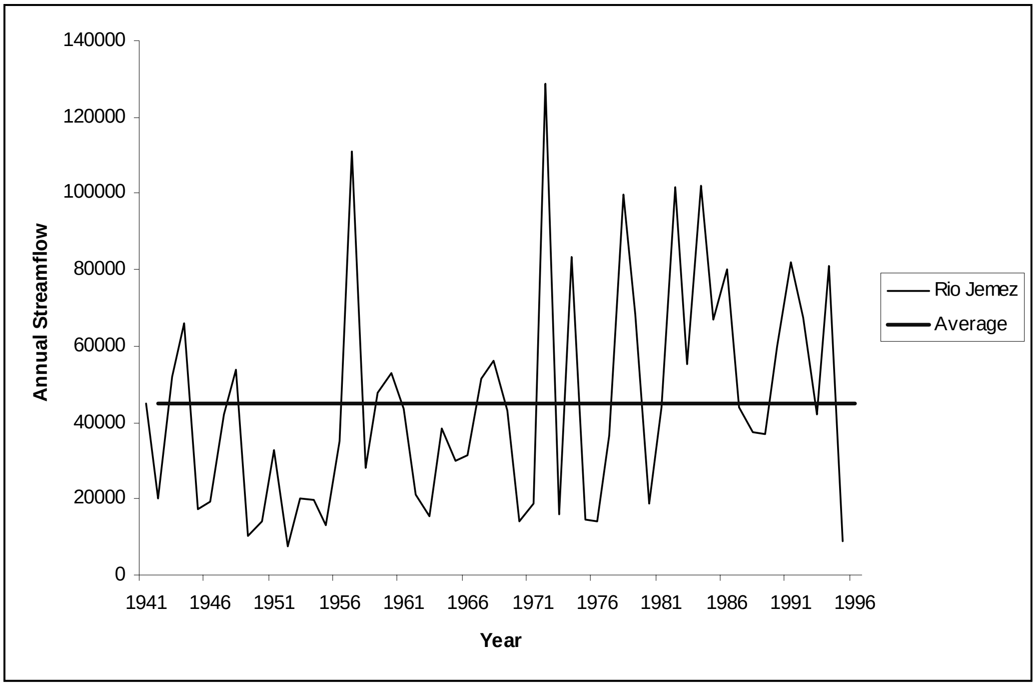
7.8 Figure 8: Conejos River Headwater Gage Annual Streamflow



7.9 Figure 9: Rio Puerco Headwater Gage Annual Streamflow



7.10 Figure 10: Jemez River Headwater Gage Annual Streamflow



8 Appendix: Total Benefits of Consumptive use for Agricultural and M&I Uses of Water Per Acre (or per household) per year, Rio Grande Basin, Colorado, New Mexico, Texas.*

Appendix Table 1. Total Benefits of Consumptive use for Agricultural and M&I Uses of Water Per Acre (or per household) per year, Rio Grande Basin, Colorado, New Mexico, Texas.*

Location	Label	State	Sector	β_0	β_1	β_2
				($)	($/acre-foot)	($/acre-foot^2)
San Luis Valley	RGWCD	CO	Ag	195	145	-14
Albuquerque	ALB	NM	M&I	0	10843	-9627
Middle Valley	MRGCD	NM	Ag	-30	67	-6
Mesilla Valley	EBID	NM	Ag	137	94	-2
El Paso	EP	TX	M&I	0	9507	-9392
El Paso	EPCWID	TX	Ag	0	193	-21

*Functional form: Total benefits = $\beta_0 + \beta_1$ (acre-feet) + β_2 (acre-feet).^{2} Here acre-feet refers to total consumptive use. Since all stream diversions are assumed to be consumptively used in the simple model used for this study, consumptive use is set equal to water diverted (i.e. zero return flows).