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Extended Abstract

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Abstract

In the Rio Grande Basin, water is over-appropriated, and demands for water grow while supplies are constrained by drought and climate change. The Basin is currently in its seventh year of drought, and reservoirs are at historically low levels. Agricultural and municipal river diversions have been sharply curtailed; low flows threaten endangered species. A central policy challenge is the design and implementation of plans that allocate the Basin's water supplies efficiently, fairly, and sustainably. Such plans are complicated by the demands of existing water users, potential new users, three state governments, and two sovereign nations. These challenges are addressed by designing and developing an integrated basin-wide nonlinear programming model to optimize water allocations and use levels for the Basin. The model permits a quantitative testing and analysis of whether institutional adjustments can limit damages caused by drought. It identifies changes in water uses and allocations that result from those adjustments. Compared to existing rules governing the Basin's water use, future drought damages could be reduced by one-fifth to one-third per year from intrastate and interstate water markets coupled with marginal cost pricing, respectively, that permit water transfers across jurisdictions. Results show hydrologic and economic tradeoffs among water uses, regions, and drought control programs.

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1 Results

1.1 Overview

Results show drought impacts starting from the severely depleted reservoir conditions existing at the end of 2005. We focus on nine scenarios representing a combination of three water supply conditions and three institutions for pricing and allocating water including the existing Law of the River. The hydrologic conditions produce three constant inflow levels to the basin for twenty two consecutive future years, 2006-2025: 100%, 75%, and 50% of long-term mean annual flows. For comparison, the lowest historical annual inflow occurred in 2002 and producing only 37% of the annual mean. The year 2006 is still in progress, but is forecast to produce even lower flows than occurred in 2002.

Basin supply and demands for the years 1998-2003 are used for model calibration. Historic Elephant Butte reservoir volumes and actual deliveries to users downstream from the reservoir were targeted, with unmeasured groundwater return flows in the reach between Cochiti Lake and Elephant Butte Reservoir the primary calibration factor. Typical model dimensions are 314 variables, 307 equations, 56 blocks of equations, 38 blocks of variables, 792 nonzero elements for each year of the 20 year solved problem. Water flows and stocks are allocated simultaneously over all years and nodes in the model, reflecting the naive assumption that the basin's planners act as if they believe that each future year's inflows at the headwater gauges will match that gauge's long run average over the period of record. Important future research needs to be conducted to find out more about the length basin managers' planning horizons and their expectation of future basin inflows. Solving the model for the current policy, the Law of the River, with a 20 year time period using MINOS nonlinear solver requires approximately 20 seconds of actual clock time. It converging after about 4000 minor iterations on a 2.2 GHZ CPU Pentium 4 PC with 1.00 GB of memory running GAMS version 22.0; solutions characterizing pure marginal cost pricing and two-tiered pricing require similar total run times.

1.2 Marginal Cost Pricing

Table 1 shows results of a program labeled as marginal cost pricing. That program consists of water allocations that meet the four institutional constraints defined above: (1) international treaty, (2) Federal Endangered Species Act, (3) Interregional Agreement, and (4) Intra-regional water sharing convention. Beyond those four institutional constraints, water is allocated to reservoir storage patterns and to water uses, and it is priced so as to maximize the present value of total regional economic and environmental benefits without constraints. As future M&I demands expand in the face of growing urban populations, water is transferred from agriculture to M&I uses.

For each use and at each node in the basin, total benefits are defined as the willingness to pay for that water's use. Total cost is the cost of meeting those demands. For agricultural uses, total net benefits are defined as total agricultural income (benefits) minus the cost of supplying water to irrigation (costs). For M&I uses, total net benefits are defined as the total water bill plus consumer surplus (benefits) minus total costs of pumping and treatment that removes pollutants from the water (costs). For water environments, total net benefits are defined as the total benefits to water-based fishing at the basin's reservoirs (benefits) minus the total cost of managing facilities to support and protect the outdoor recreation environment at those reservoirs (costs).

1.2.1 Hydrologic Impacts

Hydrologic impacts reflect the net-benefit maximizing combination of storage, release, and use patterns consistent with the four institutional constraints described previously and with a marginal cost pricing policy as described above. For Colorado agriculture, about two-thirds of average annual use comes from groundwater pumping, reflecting the comparatively low cost of pumping, and a limited legal capacity to use surface water. A large part of Colorado's surface water must be delivered downstream to the Colorado-New Mexico state line. The City of Albuquerque has no current surface treatment capacity, so its entire water supplied to its customers of 143,300 acre feet per year, averaged over the next 20 years, is met by groundwater. Surface treatment facilities are planned for future years, but they are not yet on line. Central New Mexico agriculture applies just under 100,000 acre feet per year averaged over the next 20 years. This agricultural use described is much lower the current (2006) use for irrigation, reflecting large quantities of agricultural water likely to be transferred to future M&I uses. There is no pumping capacity currently developed for that irrigation area. Total water use in New Mexico is constrained by the Rio Grande Compact, from which limited supplies are delivered by Colorado, and for which considerable amounts must be delivered to southern New Mexico and to Texas at Elephant Butte Reservoir. Southern New Mexico agriculture diverts just over 500,000 acre feet per year with little or no pumping required under a normal allottment. Recreational reservoir volumes average 2.1 million acre feet per year in the four upper basin reservoirs, and average just 80,000 acre feet per year in the southern New Mexico reservoirs. Part of this reservoir storage disparity occurs under the model's optimization goal because of the considerably lower evaporation per acre of water exposed in the upper basin reservoirs. The City of

El Paso delivers just over 150,000 acre-feet per year averaged over the next 20 years, about 40 percent of which comes from its surface treatment capacity. The rest is made up by groundwater pumping. West Texas agriculture applies just over 300,000 acre feet per year, all of which is taken from surface water.

1.2.2 Economic Impacts

Table 1 shows that pricing all water uses at their marginal cost to M&I water users is the single policy that produces the region's greatest economic benefit from its scarce water, consistent with the four institutional constraints governing water allocation described above. Total net benefits to U.S. water users would increase by $13 million per year if the International Treaty, the Rio Grande Compact, and New Mexico-Texas water sharing agreements were all eliminated. It is not known how total benefits would be altered if the Endangered Species Act constraint were eliminated, because we have not been able to measure the economic value of saving the Rio Grande Silvery Minnow.

Average annual net economic benefits are maximized at $783.6 million per year. About 71 percent of those net benefits accrue to M&I users for city water supply, measured as the total water bills plus consumer surplus minus the cost of pumping and purifying city water supply. This very high percentage of total benefits accruing to M&I users is typical for dry regions of the world containing large urban areas with a well-developed physical and institutional infrastructure for piping in good quality water into people's homes. Under these conditions the price elasticity of demand for M&I water is low, which means that people's willingness to pay for water is considerably higher than their actual price charged. Agricultural uses in the four crop-producing areas contribute about 25 percent of total net benefits, consisting of total farm income minus the cost of supplying irrigation water. As is typical in most irrigated areas, Rio Grande Basin irrigators have limited ability to pay a high price for water except for the highest-valued crops, but will demand very large quantities of water if prices are sufficiently low. Environmental net benefits produce about 3 percent of total benefits, consisting of the total willingness to pay for sport fishing at the basin's six mainstem reservoirs minus the management cost of supporting that fishing.

An important qualification of our findings is that a considerable but unknown amount of environmental values of water were not measured. We were only able to measure the economic value of sport fishing and changes in that value associated with changes in reservoir levels. Economic values of instream flows were not estimated, nor were any economic values estimated associated with measures for reducing water pollution or for the various ecosystem functions provided by protecting, improving, or restoring aquatic ecosystems. These are important areas for future research.

1.3 Efficiency, Equity, and Sustainability of Three Water Programs

Table 2 shows results for the important criteria of economic efficiency, equity, and sustainability for each of the three water policies considered for three drought scenarios. These three drought scenarios are (1) normal water inflows for the next 20 years, (2) 25% reductions, and (3) 50% reductions.   Economic efficiency is measured as average annual total net benefits summed over the two water uses and one water environment at all basin nodes. Equity is measured as the monetary value of average cost of water minus its price multiplied by the minimum requirement of 83 liters per person per day of safe and healthy water. It reflects the monetary cost of the subsidy by high-water using ratepayers to uses for essential health and safety needs. Sustainability is defined by financial sustainability, measured as the percentage of total costs of supply to M&I users recovered through its prices. Any number equal to or larger than 100 percent is considered to score high on this criterion.

The Law of the River is defined by the historical practice of permitting comparatively little water to leave agriculture and requiring M&I uses to find water to meet growing populations' needs from sources other than transfers from irrigated agriculture. All four institutional constraints defined above are kept intact, but no water is permitted to be transferred from irrigated agriculture to future M&I uses. For this reason the Law of the River shows much higher prices for M&I uses under all three drought scenarios considered. This is because the marginal cost of new M&I water increases considerably as both U.S. basin cities, Albuquerque and El Paso, are forced to turn to increased pumping to meet the needs of their growing populations at the expense of less use of cheaper surface water.   While the law of the River scores high on financial sustainability because price exceeds average cost of supply considerably. However those high prices reduce M&I use considerably compared to use under the other two policies considered, producing what could be called an unmet need for M&I uses. The considerably higher marginal benefit of water for M&I user compared to the marginal benefit in agriculture causes a reduction in the basin's overall net efficiency benefits. Total net efficiency benefits per year are a rather weak $734 million dollars for a series of full supply years. However, reservoirs and aquifers' terminal levels are at least as high as starting values, so there are zero resource costs everywhere.

The second policy considered is simple marginal cost pricing, as was described above. As stated previously, this policy produces a basin wide net economic benefit of about $783 million per year under full water supply conditions. This policy is also financially sustainable because there are no subsidies to any of the basin's users. All users pay a price equal to their marginal cost of use. Because the marginal cost of M&I uses is slightly higher than its average cost, total revenues exceed total costs, with the result that this policy passes the test of financial sustainability. Because all basin reservoirs and aquifers' ending levels are at least as high as their starting levels, this policy has zero resource costs.

The final policy examined is the policy of two-tiered pricing, which is described in more detail below. Generally, two-tiered pricing performs quite high on the economic efficiency criterion, nearly as high as marginal cost pricing performs. It performs nearly as high on efficiency grounds and higher on equity grounds than does pure marginal cost pricing for all three drought scenarios considered.

1.4 Economic Performance of Two-Tiered Pricing

Table 3 shows economic outcomes faced by all major basin users associated with a two-tiered pricing system. Recall from Table 2 that two tiered pricing is less desirable on efficiency grounds because a higher price is charged for discretionary M&I uses, is required to finance subsidized uses required for basic health and safety. That higher price for discretionary uses restricts those uses slightly compared to a scenario of pure marginal cost pricing. Total net efficiency benefits are about $782.8 million per year, a slight one tenth of one percent reduction from basin total net benefits produced under pure marginal cost pricing. Two tiered pricing scores highest on equity, producing total basinwide benefits to M&I users of $107,000 per year. This is the amount by which the costs of supplying safe and healthy water exceed the revenues collected by water utilities on those uses. Total revenues exactly match total costs through price increases charged to discretionary uses, so this program is also financially sustainable.

Table 3 emphasizes the distribution of total benefits, total costs, and total net benefits to three classes of beneficiaries: (1) M&I uses, (2), agricultural uses, and (3) water environments. The table also shows marginal benefits, marginal costs, and marginal net benefits to the same uses. Notice that marginal benefits are considerably higher than marginal costs for M&I uses because of the two tiered pricing arrangement. This occurs because marginal (discretionary) uses are priced at a level exceeding marginal cost by an amount needed to offset financial losses on water subsidies for basic human needs. A similar water pricing program has been practiced by the Metropolitan Water District of southern California since the early 1990s (Metropolitan Water District, 2006)

With sufficiently large water supplies, marginal net benefits of both larger uses and better water environments would be zero everywhere. Similarly, even with scarce water, if all four institutional constraints on water allocation were removed, marginal net benefits would be nearly equal everywhere, the only difference between the two being for high prices on discretionary M&I uses required to subsidize basic needs of health and safety.

2 Conclusions

This paper has examined the role that role played by water incentive pricing programs. These programs have considerable potential to promote economically efficient water use patterns as well as providing a revenue source to compensate for environmental damages by applying the ‘polluter pays’ principle. However incentive pricing risks imposing unfair and disproportionate costs. To deal with the undesirable equity properties of pure marginal cost pricing, this paper has presented an analysis of a two-tiered water pricing system. This system prices basic human health and safety water needs cheaply, but charges a price equal to full marginal cost including environmental cost for discretionary uses.

Using the example of the Rio Grande Basin, a nonlinear programming model is developed and applied to maximize the region’s total net economic and environmental benefits subject to the requirements that water prices and allocations are efficient, equitable, and sustainable. Supply costs, environmental costs, and resource costs are estimated and integrated into a basin-wide model of hydrology, economics, and institutions. Compared to the current law of the river and to pure marginal cost pricing, application of this model shows that two-tiered pricing scores high on efficiency, highest on equity, and high on sustainability. Findings provide a framework for formulating water pricing programs that promote economically and environmentally efficient, equitable, and sustainable water use patterns.

3 Tables

3.1 Table 1: Hydrologic and Economic Performance of Pure Marginal Cost Pricing

Table 1: Table 1: Hydrologic and Economic Performance of Pure Marginal Cost Pricing[2]

State	CO	NM_1			NM_2		TX		Basin Total[3]
Sector	Ag	M&I	Ag	Rec	Ag	Rec	M&I	Ag	
Hydrologic Performance									
Water Applied (1000 ac-ft/yr)	1777.3	143.3	98.8	2112.6[4]	513.4	82.6	161.9	309.9	3004.6
Surface water	660.5	0.0	98.8	0.0	513.4	0.0	62.0	309.9	1644.6
Groundwater	1116.8	143.3	0.0	2112.6	0.0	82.6	99.9	0.0	1360.0
Economic Performance									
Benefits ($US million/yr)	207.6	401.1	2.9	23.3	32.8	0.9	405.3	15.7	1089.6
Use	207.6	401.1	2.9	0.0	32.8	0.0	405.3	15.7	1065.4
Environmental	0.0	0.0	0.0	23.3	0.0	0.9	0.0	0.0	24.2
Costs ($US million/yr)	51.2	116.8	1.0	0.9	5.1	0.0	127.9	3.1	306.0
Use	51.2	116.8	1.0	0.0	5.1	0.0	127.9	3.1	305.1
Environmental[5]	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.9
Net Economic Benefits	156.4	284.3	1.9	22.4	27.7	0.9	277.4	12.6	783.6

[2]Tabled entries are averages per year for period 2006-2025. Pure marginal cost pricing is defined as pricing all M&I uses at their marginal costs of supply and permitting water transfers from agriculture while meeting four institutional constraints. Those constraints are (1) international treaty, (2) federal law, (3) interstate water compact, and (4) intrastate agreement.

[3]Basin totals include only water quantities used, excluding reservoir contents.

[4]Recreational water quantities applied are average annual reservoir volumes in 1000s of acre feet summed at the six reservoirs shown in table 3. For NM_1, the four upper basin reservoir contents are summed; for NM_2, the two lower basin reservoir contents are added.

[5]Environmental costs measured as management resources needed to protect a water environment that supports water-based outdoor recreation visitation.

3.2 Table 2: Efficiency, Equity, and Sustainability of Three Water Pricing Programs

Table 2: Efficiency, Equity, and Sustainability of Three Water Pricing Programs				
Water Allocation and Pricing Measure	Economic Efficiency (Total Net Benefits) $million/yr	Equity [(AC - P) x Wn][1] $ 1000/yr	Sustainability pct of costs recovered	zero resource cost[2] (Yes or No)
No ag transfers to M&I; mc pricing for M&I[3]				
full water supply	734.3	0	209	Y
drought, 25% reduction in supplies	721.5	0	209	Y
drought, 50% reduction in supplies	699.1	0	208	Y
Ag transfers to M&I; mc pricing for M&I[4]				
full water supply	783.6	0	101	Y
drought, 25% reduction in supplies	770.7	0	101	Y
drought, 50% reduction in supplies	748.3	0	101	Y
Ag transfers to M&I; 2-tiered pricing for M&I[5]				
full water supply	782.8	107.7	100	Y
drought, 25% reduction in supplies	770.0	107.7	100	Y
drought, 50% reduction in supplies	747.5	107.7	100	Y

[1]Defined as average cost of supply minus a subsidized water price set at $US 0.26/1000 liters ($ 1/1000 gal) for M&I basic needs. That need is defined as 83 liters (22 gallons) /day/person/household.

[2]Defined as sustaining aquifer and reservoir levels at critical zones and guaranteeing minimum streamflows for endangered species

[3]Achieved by maximizing regional economic benefits subject to 4 institutional constraints: (1) US Mexico Treaty of 1906, (2) Endangered Species Act of 1973, (3) Rio Grande Compact, and (4) New Mexico Texas water allocation convention (DII); Excludes water transfers from ag to M&I while pricing M&I water at its full marginal cost.

[4]Maximizes regional economic benefits constrained by four institutions above. Includes water transfers from ag to M&I while pricing M&I water at full marginal cost.

[5]Maximizes regional economic benefits constrained by four institutions above. Includes water transfers from agriculture to M&I while assuring affordable water for M&I basic needs and full M&I cost recovery.

3.3 Table 3: Economic Performance of Two Tiered Pricing

Table 3: Economic Performance of Two Tiered Pricing[1]													
State	CO	NM_1						NM_2			TX		Basin Total
Benefit Class	Use[2]	Use		Environment[3]				Use	Environment		Use		
Location	SLV	Alb	MRGCD	He	EV	Ab	Co	EBID	EB	Ca	El Paso	EPWCD	
Purpose	Ag	M&I	Ag	Rec	Rec	Rec	Rec	Ag	Rec	Rec	M&I	Ag	
Economic Indicator													
Total Benefit ($ mill)	207.6	396.6	2.9	6.7	5.5	10.0	1.1	32.8	0.5	0.4	399.7	15.7	1079.5
Total Cost ($ mill)	51.3	112.7	1.0	0.1	0.0	0.6	0.0	5.1	0.0	0.0	122.7	3.1	296.6
Total Net Benefit ($ mill)	156.3	283.9	1.9	6.6	5.5	9.4	1.1	27.7	0.5	0.4	277.0	12.6	782.8
Marginal Benefit ($)[4]	80.0	2164.0	60.5	5.8	6.6	2.0	2.5	80.8	2.1	2.2	2145.2	28.2	na
Marginal Cost ($)	57.7	1848.1	36.0	0.4	0.3	0.5	0.3	21.7	0.3	0.6	1848.1	21.7	na
Marginal Net benefit ($)[5]	22.3	315.9	24.5	5.4	6.3	1.5	2.2	59.1	1.8	1.6	297.1	6.5	na

[1] Tabled entries are annual averages per year for 2006-2025.

[2] For use nodes, locations are San Luis Valley, Colorado; Albuquerque NM, Middle Rio Grande Conservancy District; Elephant Butte Irrigation District; El Paso M&I, and El Paso Water Conservancy District Agriculture.

[3] Environment locations are water-based outdoor recreation sites. Locations are Heron, El Vado, Abiquiu, Cochiti, Elephant Butte, and Caballo reservoirs.

[4] For use nodes, marginals are in $/acre foot of added water consumed/yr; for environment nodes, marginals are in $/acre foot of added reservoir volume/yr.

[5] Marginal net benefit is marginal benefit minus marginal cost, equal to Hotelling scarcity rent. That rent equals zero at all nodes under conditions of plentiful reservoir volumes and high streamflows. That is, when volumes and flows are high everywhere, water is not the limiting resource, so water's price (marginal benefit) equals its marginal cost for all classes of uses at all nodes. That scarcity rent only exceeds zero, as shown in the table, when reservoir volumes or streamflows are constrained by water scarcity or by institutional, legal, hydrologic, technical, or physical barriers that constrain supplies at all nodes from reaching their efficient level (marginal benefit = marginal cost).