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More Reservoirs or Transfers? A Computable General Equilibrium Analysis of Projected Water Shortages in the Arkansas River Basin

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A computable general equilibrium model of the southeastern Colorado economy is used to compare the economic impacts of a proposed increase in reservoir storage to an alternative: temporary water transfers. While both provide municipalities with reliable water supply during droughts and are shown to benefit both rural and urban communities, temporary transfers are accomplished at a much lower economic and environmental cost. This analysis illustrates how computable general equilibrium models provide a more realistic portrayal of the impact of policy changes than input-output analysis by allowing substitution in response to economic conditions.

Key words: Arkansas River Basin, computable general equilibrium, drought leasing, economic analysis, temporary water transfers, water shortages

Introduction

A 1998 study commissioned by the Southeastern Colorado Water Conservancy District (SCWCD) concluded that, in order to meet increased municipal and agricultural demands through 2040, approximately 170,000 acre-feet of additional water will be required at a cost of approximately $200 million. A computable general equilibrium (CGE) model of the southeastern Colorado economy is used here to show that the net benefits of this increase in storage are similar to the impacts of allowing a relatively small increase in water transfers. Such transfers can potentially be accomplished at little or no cost, and do not cause the environmental disruption of large reservoirs.

The CGE model also shows that the impact of water transfers on agriculture is relatively small, especially if the transfers are temporary, and that the overall impact on rural communities is positive. The CGE model used in this investigation allows for behavioral changes in response to changing conditions, providing a more realistic and accurate analysis of the likely impacts of increased transfers than input-output analysis. Based on a review of current literature, this study represents one of the first efforts to use a CGE model to analyze the regional economic impacts of water reallocation, and the first to compare increased water transfers to increased storage.

The remainder of this article is organized as follows. In the section below, background information is provided on the southeastern Colorado economy as well as some discussion of the literature in this area. The next section presents the general equilibrium

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model of the southeastern Colorado economy. This is followed by a discussion of the results of a comparison between increased storage capacity and increased water transfers. The conclusions of the study are offered in the final section.

Background

The Arkansas River and its tributaries provide water to the southeastern Colorado counties that make up the Arkansas River Basin. This is a largely rural area comprising nearly one-quarter of the state of Colorado, with a total population of slightly more than 750,000 people in 1995. Most of that population (78.2%) is located in two urban centers, Pueblo and Colorado Springs. The relatively urban counties where these cities are located (Pueblo and El Paso) have a population density of 131.7 people per square mile. The rest of the region, including Bent, Chaffee, Costilla, Crowley, Custer, Fremont, Huerfano, Lake, Las Animas, Otero, Park, Prowers, Saguache, and Teller counties, is largely rural and has a density of 5.9 people per square mile.

Table 1 summarizes economic data for the Upper Arkansas Basin, based on the 1995 Colorado county-level data set produced by IMPLAN (Minnesota IMPLAN Group, Inc.). The two urban counties account for $15.2 billion, or 86% of the region's total value added (income paid to owners of factors of production), and urban employment accounts for 354,100, or 83.2% of the regional total. Production in urban counties is almost exclusively commercial and industrial. In these counties, agricultural output makes up just 0.2% of value added and 0.4% of employment. In the rural counties, agriculture remains a significant source of income for many people. In these counties, agriculture accounts directly for 5.4% of value added and 6.3% of employment. Overall, 82.9% of agricultural output is produced in the rural counties.

Table 1 also provides a breakdown of the agriculture sector to show major regional crops. Livestock production, which uses relatively little water, accounts for 55.1% of agricultural value added and 45.6% of agricultural employment in the rural counties. Vegetables, including relatively high-value crops such as carrots, cantaloupes, and onions, account for 13.9% of agricultural value added and 5.7% of employment. Hay and pasture, and other low-value crops such as corn, wheat, and sorghum, account for most of the rest. Table 2 shows the revenue generated per acre for a variety of crops.

According to 1995 Colorado Water Resources Research Institute data, about 830,000 acre-feet of water is available for consumptive use in the Arkansas River Basin in an average year. This includes 730,000 acre-feet of native Arkansas River water and 100,000 acre-feet of non-native water diverted from the Fryingpan River in western Colorado. The non-native water is freely transferable, and cities and farmers transfer this water on a temporary or permanent basis. About 85% of the available water is used for irrigation of agricultural crops. In addition, irrigation water rights on average have earlier appropriation dates than municipal rights. Based on Colorado's prior appropriation doctrine, water rights with earlier appropriation dates are required to receive their full allotment of water before others receive theirs. Thus, in a dry year, an even higher percentage of available water goes to irrigate agricultural crops. As the region's urban population continues to grow, the need for reliable municipal water supplies increases correspondingly.

The SCWCD study focuses largely on traditional solutions to these increased water needs, including expansion of existing reservoirs and construction of new reservoirs. But

Table 1. Summary of Economic Data: Value Added and Employment in Southeastern Colorado, 1995

RURAL COUNTIES

Rural Agricultural Economy	Value Added ($ mil.)	% of Rural Agriculture	Employment	% of Rural Agriculture
Livestock	73.75	55.1	2,070	45.6
Hay and Pasture	26.11	19.5	1,801	39.7
Feed Grains	7.57	5.7	152	3.4
Food Grains	7.07	5.3	233	5.1
Vegetables	18.54	13.9	258	5.7
Other Crops	0.78	0.6	23	0.5
Total Rural Ag Economy	133.82		4,537	

Rural Total Economy	Value Added ($ mil.)	% of Rural Total	Employment	% of Rural Total
Agriculture	133.82	5.4	4,537	6.3
Industry	414.88	16.7	11,453	16.0
Commerce	1,934.02	77.9	55,737	77.7
Total Rural Economy	2,482.72		71,727	

URBAN COUNTIES

Urban Agricultural Economy	Value Added ($ mil.)	% of Urban Agriculture	Employment	% of Urban Agriculture
Livestock	13.42	48.5	657	47.6
Hay and Pasture	5.71	20.6	569	41.3
Feed Grains	1.72	6.2	43	3.1
Food Grains	0.53	1.9	22	1.6
Vegetables	6.08	22.0	82	5.9
Other Crops	0.22	0.8	6	0.4
Total Urban Ag Economy	27.68		1,379	

Urban Total Economy	Value Added ($ mil.)	% of Urban Total	Employment	% of Urban Total
Agriculture	27.68	0.2	1,379	0.4
Industry	2,698.56	17.8	56,647	16.0
Commerce	12,465.77	82.1	296,074	83.6
Total Urban Economy	15,192.01		354,100	

TOTAL REGION

Regional Economy	Value Added ($ mil.)	Rural % of Regional Totals	Employment	Rural % of Regional Totals
Agriculture	161.50	82.9	5,916	76.7
Industry	3,113.44	13.3	68,100	16.8
Commerce	14,399.79	13.4	351,811	15.8
Total Regional Economy	17,674.73	14.0	425,827	16.8

Note: Percentages may not total to 100 due to rounding errors.

Table 2. Irrigated Crop Revenue in Southeastern Colorado, 1995

Crop	Irrigated Acreage	% of Total	Crop Revenue ($)	% of Total	Revenue per Acre ($)
Onions	1,854	0.43	7,163,856	5.58	3,864
Carrots	147	0.03	942,638	0.73	6,413
Cantaloupes	952	0.22	1,405,152	1.09	1,476
Corn	81,500	18.70	28,116,969	21.89	345
Hay	258,200	59.24	75,567,910	58.84	293
Wheat	63,000	14.45	11,308,428	8.81	179
Sorghum	30,200	6.93	3,922,422	3.05	130
Totals	435,853		128,427,375		

Note: Percentages may not total to 100 due to rounding errors.

the study also briefly mentions some "nonstructural water management" alternatives, including water transfers. Drought leasing, or contingency contracts under which municipalities purchase the right to use agricultural water only during drought conditions, received the most serious consideration at two pages, compared to 45 pages for study of storage alternatives.

The SCWCD study states that drought leasing "could help to reduce the amount of storage needed by municipal users. This, [in] turn, would help keep more land in agriculture, and reduce the size of the reservoirs necessary to provide dependable water supply to the municipal users" (p. 8-46). The study goes on to state that while water rights transfers from agricultural to municipal users tend to harm agriculture, this may not be the case for all transfers. "If the municipal users continue to pursue the outright purchase of senior water rights, it will exacerbate the current competitive environment, resulting in rising water prices and diminishing the agricultural base of the District. However, a leasing concept may actually aid the agricultural economy" (p. 8-46).

Proposals to transfer water have generally met with considerable resistance and public opposition, in part due to the popular belief that these transfers decimate rural communities. A 1998 report by the Western Water Policy Review Advisory Commission states that "transfers make sense when they meet new demands and do not impair . . . the rural communities historically dependent on adequate water supplies" (p. 3-22). But the Commission also recognizes that "water transfers are an essential part of any discussion of the future of the West and its water" (p. 6-26).

A study by Howe, Lazo, and Weber used input-output analysis to analyze the impacts of several Arkansas River water rights transfers then under consideration. The authors concluded that while these permanent transfers would produce net welfare gains, the benefits would go to the urban areas while the costs would be borne by the rural areas. The transfers would reduce agricultural production permanently, in direct proportion to the reduction in water used in agriculture. This reduction in agriculture results in direct employment and income effects and has a negative multiplier effect on agriculture-dependent industrial and commercial activities in rural communities.

The input-output analysis used by Howe, Lazo, and Weber is likely to provide an incomplete picture of the impacts of water transfers. While water transfers undoubtedly cause disruption for agriculture-dependent rural communities, they also provide income to these communities. Hamilton, Whittlesey, and Halverson estimated that the gains to hydropower production would be 10 times the losses to agriculture, if drought leasing were permitted on the Snake River. This would allow farmers to be adequately compensated and still result in substantial net gains.

Seung et al. concluded that permanent water transfers in the Walker River Basin of Nevada and California will result in a small net decrease in regional income, after income transfers are considered. While Seung et al. used a general equilibrium model, so that income transfers were accounted for, the model assumed a Leontief production function where land and water have a zero elasticity of substitution. This led to their conclusion that transfers produce a net negative impact on agriculture, similar to an input-output model. By testing a variety of assumptions about substitutability, as well as accounting for income transfers, the general equilibrium model of the southeastern Colorado economy used here seeks to provide a more complete and accurate portrayal of the impacts of transfers.

Model Specification

The southeastern Colorado regional model is set up with four factors of production: land (N), labor (L), capital (K), and water (W); and four productive sectors: irrigated and nonirrigated agriculture, commerce, and industry (sectors $s = IRRAG, DRYAG, COM$, and IND). The labor force is assumed to grow at the same rate as the population, and net investment is assumed to be sufficient to make the capital stock grow at the same rate. But the stocks of land and water are fixed in supply, so that these factors become increasingly scarce over time. Labor is assumed to be mobile between sectors, while capital is sector-specific. Land and water are assumed to be use-specific, indicating that they may be designated either for municipal or agricultural use (uses $q = MUN, AG$), where municipal use includes domestic, commercial, and industrial uses.

General Equilibrium Economic Model

There are two regional representative agents, rural and urban ($r = RUR, URB$), who maximize utility subject to the value of income derived from their resource endowments. Utility for each regional agent (U_r) is a constant elasticity of substitution (CES) function[1] of the discounted present value of consumption in each period t ($C_{r,t}$), as shown in equation (1):

$$(1) \qquad U_r = \sum_{t=1}^{T} \left(\frac{C_{r,t}^{\rho_t}}{(1+i)^{t-1}} \right)^{1/\rho_t},$$

where i is the interest rate, and ρ_t is based on the intertemporal elasticity of substitution σ_t ($\sigma_t = 1/(1 - \rho_t)$).

[1]The CES function is used for utility, consumption, and production because it is a flexible form, encompassing several other functional forms. For instance, a substitution elasticity value of 0 is equivalent to a Leontief production function, while a value of 1 is equivalent to a Cobb-Douglas production function. The elasticities can then be altered within the model to identify the sensitivity of the results to these assumed values.

Income in each region (I_r) from resource endowments is the discounted present value of income in each period from labor (L_t), land ($N_{q,t}$), water ($W_{q,t}$), and capital ($K_{s,t}$), as shown in equation (2):

$$(2) \qquad I_r = \sum_{t=1}^{T} \frac{1}{(1+i)^{t-1}} \left(L_{r,t} pl_t + \sum_q \left(N_{r,q,t} pn_{q,t} + W_{r,q,t} pw_{q,t} \right) + \sum_s K_{r,s,t} pk_{s,t} \right).$$

The subscript q for land and water indicates that these factors are use-specific as described earlier, while the subscript s indicates that capital is sector-specific. Here pl, pn, pw, and pk are the respective prices of labor, land, water, and capital.

To accurately measure the impacts of changes in production on urban and rural regions, ownership of each factor of production is allocated to those regions. In addition to labor and capital, this model also incorporates land and water as factors. Labor income is provided in the IMPLAN data set, but all other income is aggregated into an "other property income" category. For this model, it was necessary to allocate other property income into income due to land, water, and capital.

Land endowments were estimated using information on land use and valuation from the Colorado Department of Local Affairs, Division of Property Taxation (DPT). Land acreage, and the assessed valuation of that land, are available for every county by the type of use: commercial, industrial, agricultural, and residential. Income from land, or the rental value of the annual use of land, was imputed from the value of land in each use based on assessed valuation.

Water endowments were estimated by combining U.S. Geological Survey (USGS) county-level water use data with information on annual water leases from the Pueblo Board of Water Works. The Board sells water to municipal and industrial users at \$100–\$125 per acre-foot, while it sells water to agricultural users at \$3–\$20 per acre-foot. For the purposes of this study, water is assumed to have a marginal value of \$20 per acre-foot in agricultural uses, and \$100 per acre-foot in municipal uses. This is a relatively conservative assumption of the differential in marginal valuation of water uses (e.g., Colby cited a number of studies where municipal water valuations were calculated at \$100–\$300 per acre-foot, with agricultural values ranging from \$10–\$50 for crops such as wheat, corn, and sorghum).

Income from land and water was then subtracted from the "other property income" category, with the remaining income assigned to capital. While county-level land, labor, and water data allow income to be assigned to the rural and urban agents, information on capital ownership is not available at the county level. Income from capital was assigned by first calculating the income from capital in each production sector, and then assigning income to each agent based on the percentage of that production sector in each region.

Consumption is modeled as a nested CES function, as shown in equation (3):

$$(3) \qquad C_{r,t} = \left[\left(\sum_g \left(\alpha_D D_{g,t}^{\rho_m} + \alpha_M M_{g,t}^{\rho_m} \right)^{\rho_c/\rho_m} + \sum_{s \forall q} \alpha_N N_{MUN,t}^{\rho_c} \right)^{\rho_{wc}/\rho_c} + \sum_{s \forall q} \alpha_W W_{MUN,t}^{\rho_{wc}} \right]^{1/\rho_{wc}}.$$

Note that land and water go directly into the consumption function. This refers to the use of these resources on an annual basis for residential purposes. The value share (α) of each good in consumption is estimated from the IMPLAN expenditure data. The shares of land and water in consumption are estimated from Colorado DPT residential land valuation data and USGS domestic water use data, as discussed earlier. Water and all other goods in consumption have an elasticity of substitution $\sigma_{wc} = 1/(1 - \rho_{wc})$. Land and other consumption goods ($g = AG, COM, IND$) are nested with elasticity of substitution $\sigma_c = 1/(1 - \rho_c)$. Domestic ($D$) and imported ($M$) goods are modeled as Armington goods with a high elasticity of substitution $\sigma_m = 1/(1 - \rho_m)$, recognizing the lack of significant differentiation between output of this region, the rest of Colorado, and the United States.

The IMPLAN data set includes information on 528 production sectors, which are aggregated into three sectors: agricultural, commercial, and industrial production. Additionally, agricultural production is separated into irrigated and nonirrigated sectors, based on data from *Colorado Agricultural Statistics* (Colorado Department of Agriculture). Each sector contributed about half of the total annual agricultural output in 1995. Although nonirrigated agriculture uses only precipitation, it requires about 70% of agricultural land to produce 51% of the output.

Each production sector ($s = IRRAG, DRYAG, COM, IND$) is modeled as a nested CES function, as shown in equation (4):

$$(4) \qquad Y_{s,t} = \left[\left(\sum_{g} \left(\beta_D D_{g,t}^{\rho_m} + \beta_M M_{g,t}^{\rho_m} \right)^{\rho_y/\rho_m} + \beta_K K_{s,t}^{\rho_y} + \sum_{s\forall q} \beta_N N_{q,t}^{\rho_y} \right)^{\rho_{wy}/\rho_y} + \sum_{s\forall q} \beta_W W_{q,t}^{\rho_{wy}} \right]^{1/\rho_{wy}}.$$

The value share (β) of each input in the production function is estimated using the IMPLAN cost data. Water is substitutable with other inputs, with elasticity of substitution $\sigma_{wy} = 1/(1 - \rho_{wy})$. Land, labor, and capital are then nested along with intermediate inputs, with elasticity of substitution $\sigma_y = 1/(1 - \rho_y)$. Domestic and imported intermediates are again assumed to be Armington goods as intermediate inputs.

Production is not distinguished by urban or rural areas, allowing for the possibility of factor mobility between these areas. Water and land are specified by use, however, so that, at least initially, they cannot be moved from agricultural to municipal uses. Since agriculture is produced largely in rural areas, these factors are limited in mobility by this restriction. Labor and capital are not limited by use, and thus they are mobile within the region. Regional factor ownership is assumed not to change, however, so that within-region migration does not occur. Additionally, there is assumed to be no new migration of labor as a result of the changes in water availability considered in the model.[2]

The initial capital stock is calculated based on the value share of capital in production. Investment is assumed to be sufficient to account for depreciation (δ), as well as any growth in the capital stock, to maintain that value share of production throughout the period of the model. This relation is shown as follows:

$$(5) \qquad K_{s,t+1} = (1 - \delta)K_{s,t} + I_t.$$

[2] The annual population growth rate of 2.3% is based on projections of natural growth of the population plus expected net immigration. The CGE model assumes that no change in net migration occurs as a result of changing water availability. This assumption is unlikely to affect the conclusions of the model, because there is little impact on the average wage as a result of increased storage or transfers. The average increase in wages is 0.05% for increased storage and 0.01% for increased transfers.

Capital (K) is sector-specific once investment (I) has occurred, although investment is not sector-specific. Thus the capital stock can be reallocated over time by allowing the existing stock to depreciate in some sectors and diverting investment into others.

Water is a resource that must either be used immediately in production or stored for future use. As it is renewable, an equal amount is generally available in each normal year. But because the amount of water available is dependent on climate conditions, the amount received in one year may be substantially more or less than in a normal year. According to Colorado Division of Water Resources data, in 1997, about 25% of agricultural water rights on the Arkansas River were relatively senior, defined here as having an appropriation date before May 1887.[3] In contrast, only about 10% of municipal water rights are senior. Based on yield data from various water rights provided in the SCWCD study, a senior right yields about 60% of its normal yield in a dry year, while a junior right yields about 20% of normal.

As shown in equation (6), the amount of water available for municipal use in period t ($W_{MUN,t}$) equals the actual yield (Y) in period t times the amount of rights ($R_{MUN,t}$) owned by municipalities:

$$(6) \qquad W_{MUN,t} = R_{MUN,t} * Y_t + (1 - \theta)WT_{AGR,t} - WT_{MUN,t} + SU_{MUN,t} - SW_{MUN,t}.$$

In addition, water can be stored, so that the amount of water available includes any storage water used (SU) minus any water that is stored for future use (SW). Any water transfers from agricultural use ($WT_{AGR,t}$) increase available water, but include any applicable transaction costs (θ).

The storage of water in equation (7) is similar to the capital stock in equation (5), except that instead of depreciation there is evaporation (ε):

$$(7) \qquad S_{q,t+1} = (1 - \varepsilon)S_{q,t} - SU_{q,t} + SW_{q,t}.$$

The amount of stored water available in period $t + 1$ ($S_{q,t+1}$) is dependent on annual evaporation of the water stored in period t ($S_{q,t}$). In addition, use of storage water (SU) results in a direct reduction in the stock of storage water remaining. Addition of water (SW) to storage increases the stock.

Dynamic CGE Model

The equations describing the general equilibrium economic model can be expressed as a CGE model, using the mathematical formulation described by Rutherford (1999). An economic model that satisfies the three conditions of an Arrow-Debreu general equilibrium can be expressed as a nonlinear system of inequalities. These conditions are: exhaustion of product (no economic profit in any production sectors), market clearance (no excess demand in any markets), and income balance (consumption cannot exceed income from endowments).

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[3] Two major agricultural users, the Fort Lyons Canal and the Bessemer Ditch, have substantial rights with this appropriation date. Rights with appropriation dates after this are commonly "called out," or required to shut off their diversions, during dry years.

Table 3. Model Parameter Values for Substitution Elasticities and Value Shares of Water

Parameter	Elasticity of Substitution between:	Value
σ_{wc}	Water and other goods in consumption	0.1, 0.25, 0.5
σ_{wa}	Water and other goods in agricultural production	0.1, 0.25, 0.5
σ_{wi}	Water and other goods in nonagricultural production	0.1, 0.25, 0.5
σ_c	Other goods in consumption	0.5
σ_a	Other inputs in agricultural production	0.5
σ_i	Other inputs in nonagricultural production	0.5
σ_t	Consumption in different time periods	0.5
σ_m	Domestic and imported goods	4.0
Parameter	**Share of Water in:**	**Value (%)**
α_w	Consumption	0.005
β_{wa}	Agricultural production	1.5
β_{wi}	Nonagricultural production	0.004

The CGE model was calibrated to an initial benchmark equilibrium using the IMPLAN data set. Following Rutherford (1995), the CES production functions were expressed in calibrated-share form. This form specifies the value share, or the percentage of per unit cost of each factor in each production function, based on the prices and quantities in the data set. Elasticities of substitution are the only parameters not determined directly from the data set, and were given estimated values consistent with those used in other studies (such as Seung et al.). Parameter values for substitution elasticities and value shares of water used in the model are reported in table 3. All elasticities not directly involving water were held constant in the results presented here, as the results were not sensitive to these values. The elasticities involving water in production and consumption were tested for values of 0.1, 0.25, and 0.5.

After the CGE model was benchmarked to the 1995 base year data, it was then set up as a dynamic model to simulate the economy throughout the 2000–2040 period based on the SCWCD study. The dynamic model used the SCWCD study's projected "high" population growth rate of 2.3% in southeastern Colorado, with a real interest rate of 2% to discount future periods.[4] (The model and data are available from the author upon request and were solved using GAMS version 2.50 with PATH version 4.0 and MPS/GE.)

Results

The benchmark model (BM) was set up as a "business-as-usual" scenario against which to compare the alternatives of increased storage or transfers. Because the CGE model is a perfect foresight model, dry and wet years were assumed to alternate with normal

[4] The agents maximize utility, or the expected net present value of consumption, over the 2000–2040 period. To ensure consideration of periods after 2040, the representative agents are required to maintain sufficient capital stocks and water storage for the post-2040 period. Lau, Pahlke, and Rutherford provide a detailed explanation of the issues associated with dynamic CGE models.

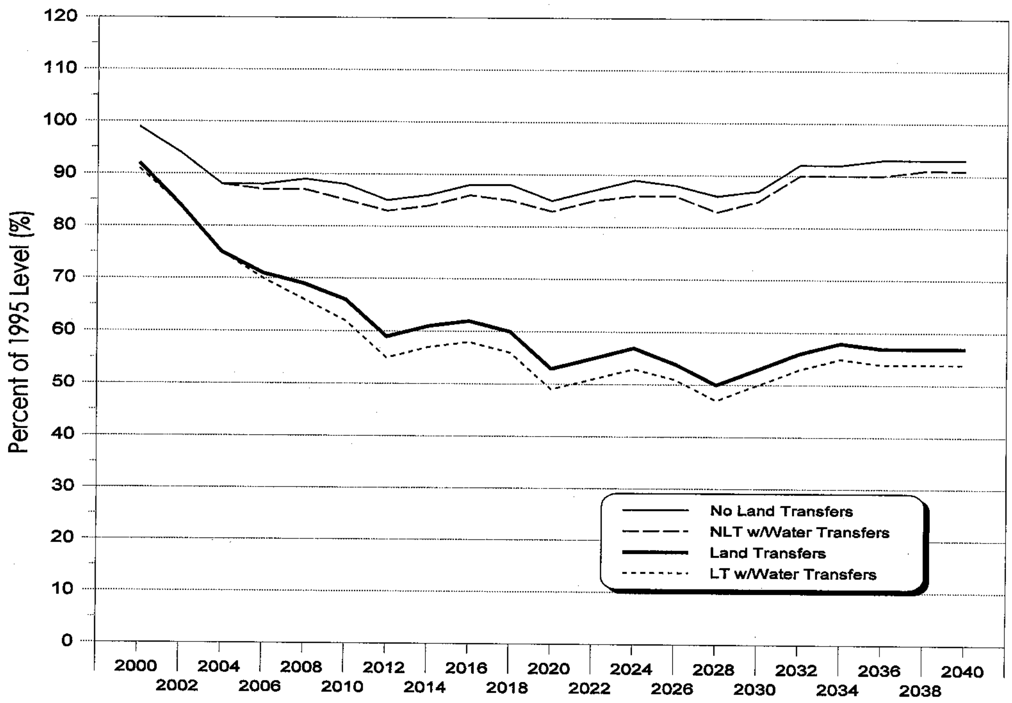

Figure 1. Projected agricultural output (% of 1995 level) by scenario, 2000–2040

years to prevent strategic water storage or investment. The increased storage scenario (ST) adds 170,000 acre-feet of storage capacity, the amount proposed in the SCWCD study. The increased transfers scenario (TR) allows water transfers to include 10% of native water, or roughly 73,000 acre-feet.

The results are presented for a variety of elasticities of substitution, with the results for the 0.25 and 0.5 values appearing to give better approximations of reality. For instance, the average acre-foot price of municipal water rises to over $7,000 in the benchmark scenario with an elasticity value of 0.1 for municipal uses and 0.25 for agricultural uses, with a high of over $30,000 per acre-foot during a drought period. These prices indicate that an elasticity of 0.1 probably understates the ability to substitute between water and other factors in consumption and production. The average acre-foot price is just over $500 in the benchmark scenario with an elasticity of 0.25, with a high of less than $1,400.

The benchmark model was solved for two cases, one in which land can be transferred from agricultural to municipal use, and one in which land remains in its original use. The impact of being able to transfer land on agricultural output is dramatic, as shown in figure 1 (using the case where substitution elasticities are equal to 0.25 for water in all production and consumption). If land is transferable, agricultural output falls to less than 60% of its 1995 level by 2040. If land is kept in agriculture, output falls by less than 10% of its 1995 level. This interesting result highlights the fact that land transfers are likely to be the most important factor in reducing agriculture over time.

When land is transferred from agriculture to municipal use, it is not likely to be a temporary transfer. Residential housing or commercial buildings are constructed, taking

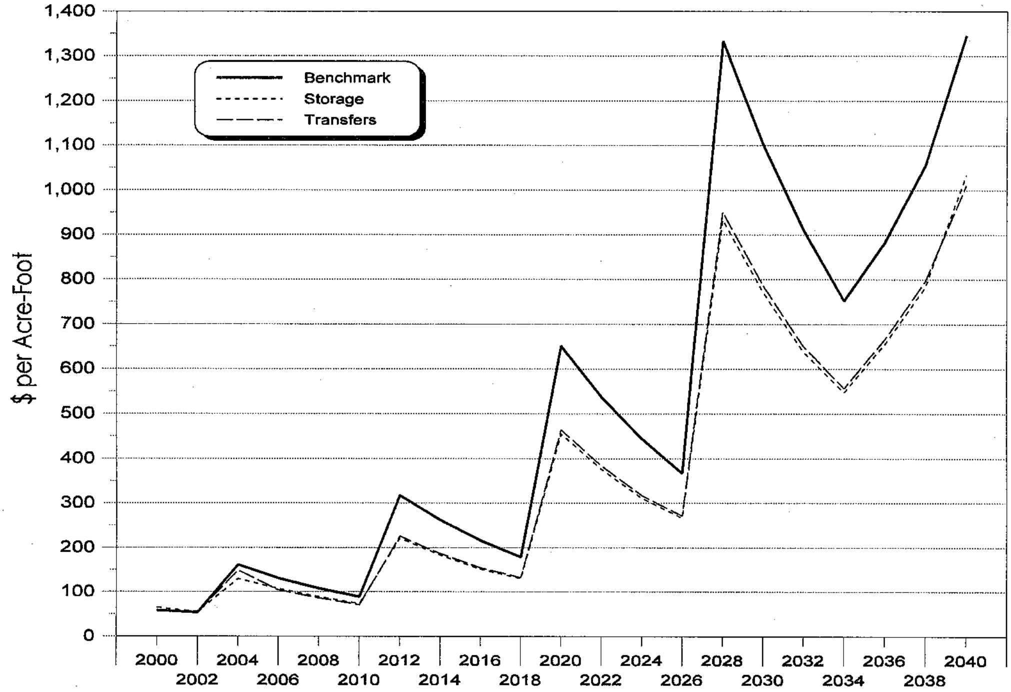

Figure 2. Projected municipal water price, 2000–2040

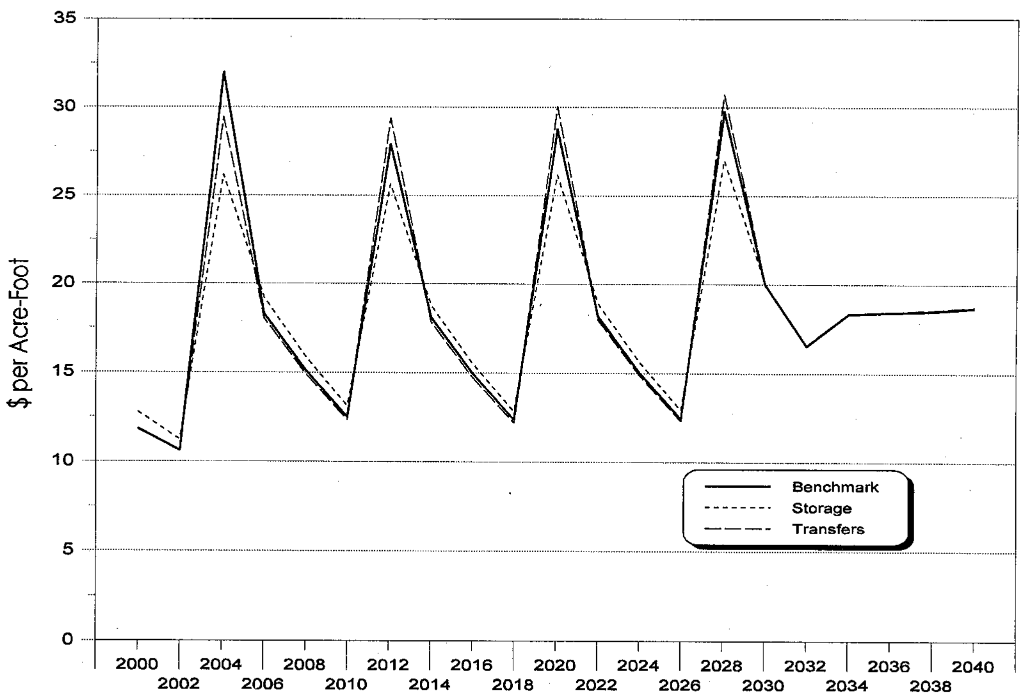

Figure 3. Projected agricultural water price, 2000–2040

Table 4. Average Regional Welfare Change, 2000–2040

Substitution Elasticities: Municipal, Agricultural	Scenario[a]	EQUIVALENT VARIATION WELFARE CHANGE (%)			
		No Land Transfers		Land Transfers	
		Urban	Rural	Urban	Rural
0.1, 0.1	ST	[No Solution]		0.52	1.28
	TR			0.43	1.04
0.1, 0.25	ST	0.51	1.27	0.52	1.28
	TR	0.43	1.02	0.43	1.05
0.1, 0.5	ST	0.52	1.27	0.52	1.28
	TR	0.43	1.02	0.43	1.05
0.25, 0.1	ST	0.01	0.04	0.01	0.04
	TR	0.01	0.05	0.01	0.06
0.25, 0.25	ST	0.01	0.04	0.01	0.03
	TR	0.01	0.05	0.01	0.06
0.25, 0.5	ST	0.01	0.04	0.01	0.04
	TR	0.01	0.05	0.01	0.06
0.5, 0.1	ST	0.00	0.02	0.00	0.01
	TR	0.01	0.01	0.01	0.02
0.5, 0.25	ST	0.00	0.01	0.00	0.01
	TR	0.01	0.01	0.01	0.02
0.5, 0.5	ST	0.00	0.01	0.00	0.01
	TR	0.01	0.01	0.01	0.02

[a] Scenarios are defined as follows: ST = storage, TR = transfers.

the land out of agricultural use permanently. Water transfers may be permanent or temporary, and there is much greater flexibility in transferring use for short periods of time. The marginal impact of allowing increased water transfers on agricultural output is an additional 2% reduction by 2040, relative to the benchmark scenario where both elasticities are 0.25. The impact of allowing increased storage is to increase agricultural output by less than 1%.

Figures 2 and 3 show the time path of the price of municipal and agricultural water, respectively, again using the 0.25 substitution elasticity value for water in production and consumption. The results shown are for the scenario with no land transfers, which is virtually identical to the time path in the scenario with land transfers. In the benchmark, the municipal water price (figure 2) reaches a high of nearly $1,400 per acre-foot in drought periods and at the end of the model period. In the increased storage and transfer scenarios, the municipal water price is significantly lower in drought periods, and only exceeds $1,000 per acre-foot at the end of the model period. For the time path of the price of agricultural water (figure 3), in all three scenarios it rises to about $30 per acre-foot during drought periods and falls to about $15 per acre-foot during wet periods.

Table 4 shows the equivalent variation welfare change for the rural and urban representative agents due to increased transfers (TR) and increased storage (ST), for a variety of substitution elasticities between water and other factors. Although the scale of the gain varies depending on the elasticity values, the gains from increased transfers are generally consistently positive for both regions, and similar to the gains from increased storage. Lower substitution elasticities result in higher welfare gains from allowing increased storage or transfers.

These findings run counter to the results from an I-O model, which would predict gains from increased storage, but substantial economic losses to the rural agent from an increase in transfers from agricultural to municipal use. In the case of increased storage, the benefits to the rural region can be explained as an improved ability to store water that results in increased irrigated agricultural production. In the case of increased transfers, the rural region gains primarily through increased income from water sales to municipal uses.

Table 5 reports the impact of the alternative scenarios on irrigated, nonirrigated, and total agricultural output under the same set of assumptions. The results are relatively consistent across all elasticity values, with an average decrease in total agricultural output of about 5% for increased transfers, and an increase of less than 1% for increased storage. In the scenario where both substitution elasticities are 0.25, irrigated agriculture falls by about 8% in the increased transfers scenario, while nonirrigated agriculture increases by approximately 3%.

Table 6 shows the average effect of the alternative scenarios on municipal and agricultural water prices. The impact on average agricultural water price is generally less than a 3% increase or decrease. The impact on average municipal water price percentage change is primarily dependent on the elasticity of substitution in consumption, decreasing 13–15% for a value of 0.5, and 26–28% for a value of 0.25.

Conclusions

Using the assumption that the outcomes of the models with substitution elasticities of 0.25 or 0.5 are more reasonable, the predicted welfare gains from increased storage or transfers are relatively small both for urban and rural areas. The gain is roughly 0.01% for each from increased storage, and about 0.05% for each from increased transfers. Based on 1995 output of $12 billion for the urban areas and $2.7 billion for the rural areas, that equals an average annual benefit of about $1.2 million and $1.35 million, respectively.

Increased storage capacity is a traditional answer to projected water shortages, and this model shows that it does result in some modest benefits to both rural and urban regions. However, preliminary estimates of the cost of the increased storage proposed in the SCWCD study are approximately $200 million, substantially in excess of the net present value of total projected benefits. In the face of increased demands for government funding, and with extensive environmental objections to new reservoirs a virtual certainty, it makes sense to begin to consider other options.

The benefits from increased transfers of water are generally as high or higher than those from increased storage in this model, and both rural and urban regions benefit from these transfers. Temporary water transfers have the potential to be accomplished at little or no additional cost, especially if water authorities can reduce the legal barriers to these transfers. While the third-party impacts of these transfers should continue to be considered, the temporary nature of the impacts should also be taken into consideration.

Table 5. Average Change in Irrigated, Nonirrigated, and Total Agricultural Output, 2000–2040

Substitution Elasticities: Municipal, Agricultural	Scenario[a]	PERCENTAGE OF 1995 OUTPUT: No Land Transfers: Nonirrigated: Level	Nonirrigated: % Change from BM	Irrigated: Level	Irrigated: % Change from BM	Total: Level	Total: % Change from BM	Land Transfers: Nonirrigated: Level	Nonirrigated: % Change from BM	Irrigated: Level	Irrigated: % Change from BM	Total: Level	Total: % Change from BM
0.1, 0.1	BM							0.41		0.85		0.62	
	ST			[No Solution]				0.41	−0.21	0.86	1.52	0.63	0.94
	TR							0.41	−0.17	0.77	−8.65	0.59	−5.81
0.1, 0.25	BM	0.44		0.91		0.67		0.43		0.84		0.63	
	ST	0.44	−0.22	0.93	2.64	0.68	1.68	0.43	−0.57	0.86	1.29	0.64	0.65
	TR	0.44	0.07	0.83	−8.20	0.63	−5.43	0.44	1.69	0.77	−8.81	0.60	−5.16
0.1, 0.5	BM	0.44		0.95		0.69		0.44		0.81		0.62	
	ST	0.44	−0.21	0.97	2.02	0.70	1.30	0.43	−2.31	0.82	1.06	0.62	−0.17
	TR	0.44	0.06	0.87	−7.90	0.65	−5.32	0.44	0.03	0.74	−7.99	0.59	−5.08
0.25, 0.1	BM	0.93		0.86		0.90		0.41		0.84		0.62	
	ST	0.92	−1.25	0.89	2.93	0.90	0.72	0.41	−0.01	0.86	1.30	0.63	0.86
	TR	0.96	3.76	0.79	−8.81	0.88	−2.16	0.41	−0.01	0.77	−8.67	0.59	−5.78
0.25, 0.25	BM	0.93		0.86		0.89		0.43		0.83		0.62	
	ST	0.92	−1.10	0.88	2.62	0.90	0.65	0.42	−0.15	0.84	1.32	0.63	0.80
	TR	0.96	3.64	0.78	−8.74	0.87	−2.16	0.44	2.37	0.76	−8.32	0.59	−4.59
0.25, 0.5	BM	0.94		0.84		0.89		0.42		0.80		0.61	
	ST	0.93	−0.90	0.86	2.22	0.90	0.54	0.42	−0.16	0.81	1.15	0.61	0.69
	TR	0.97	3.37	0.77	−8.38	0.87	−2.08	0.43	1.95	0.74	−7.83	0.58	−4.36
0.5, 0.1	BM	0.93		0.86		0.90		0.45		0.83		0.63	
	ST	0.92	−1.12	0.88	2.33	0.90	0.50	0.43	−2.54	0.84	1.37	0.63	−0.03
	TR	0.97	3.64	0.79	−8.86	0.88	−2.24	0.45	0.22	0.76	−8.41	0.60	−5.31
0.5, 0.25	BM	0.94		0.86		0.90		0.43		0.83		0.62	
	ST	0.93	−0.84	0.87	2.05	0.90	0.51	0.43	−0.19	0.84	1.21	0.63	0.72
	TR	0.97	3.53	0.78	−8.78	0.88	−2.23	0.44	2.39	0.76	−8.38	0.59	−4.62
0.5, 0.5	BM	0.94		0.85		0.89		0.43		0.81		0.61	
	ST	0.94	−0.68	0.86	1.70	0.90	0.42	0.42	−0.17	0.81	1.11	0.62	0.66
	TR	0.97	3.25	0.77	−8.38	0.88	−2.13	0.43	1.98	0.74	−7.86	0.59	−4.36

[a] Scenarios are defined as follows: BM = benchmark, ST = storage, TR = transfers.

Table 6. Average Change in Regional Municipal and Agricultural Water Prices, 2000–2040

Substitution Elasticities: Municipal, Agricultural	Scenario [a]	No Land Transfers: Municipal Price ($)	No Land Transfers: Municipal % Change from BM	No Land Transfers: Agricultural Price ($)	No Land Transfers: Agricultural % Change from BM	Land Transfers: Municipal Price ($)	Land Transfers: Municipal % Change from BM	Land Transfers: Agricultural Price ($)	Land Transfers: Agricultural % Change from BM
		PRICE PER ACRE-FOOT (changes based on 1995 prices)							
0.1, 0.1	BM	[No Solution]				7,078.56		16.81	
	ST					3,006.02	−57.53	15.63	−7.01
	TR					3,607.38	−49.04	16.89	0.49
0.1, 0.25	BM	7,022.38		23.35		7,080.80		16.42	
	ST	2,987.09	−57.46	22.99	−1.53	3,009.31	−57.50	15.88	−3.32
	TR	3,578.03	−49.05	23.79	1.90	3,608.42	−49.04	16.76	2.03
0.1, 0.5	BM	7,023.75		23.26		7,084.81		16.82	
	ST	2,987.98	−57.46	23.02	−1.03	3,012.65	−57.48	16.50	−1.91
	TR	3,579.61	−49.04	23.79	2.27	3,610.52	−49.04	17.26	2.61
0.25, 0.1	BM	522.03		18.42		522.83		16.10	
	ST	379.90	−27.23	18.12	−1.64	376.95	−27.90	15.40	−4.39
	TR	384.35	−26.38	18.39	−0.20	384.53	−26.45	16.56	2.84
0.25, 0.25	BM	521.94		18.51		523.14		16.65	
	ST	379.98	−27.20	18.22	−1.55	378.10	−27.73	16.17	−2.91
	TR	384.60	−26.31	18.49	−0.11	385.15	−26.38	16.90	1.52
0.25, 0.5	BM	522.37		18.49		524.37		16.92	
	ST	380.04	−27.25	18.30	−1.05	379.18	−27.69	16.66	−1.51
	TR	384.97	−26.30	18.63	0.74	385.71	−26.44	17.33	2.43
0.5, 0.1	BM	209.76		18.47		209.46		16.39	
	ST	179.11	−14.61	18.33	−0.73	177.72	−15.15	15.95	−2.66
	TR	180.81	−13.80	18.59	0.69	180.28	−13.93	16.87	2.95
0.5, 0.25	BM	209.71		18.61		209.35		16.82	
	ST	179.22	−14.54	18.34	−1.43	177.84	−15.05	16.50	−1.89
	TR	180.96	−13.71	18.64	0.14	180.53	−13.77	17.10	1.68
0.5, 0.5	BM	209.73		18.62		209.63		17.13	
	ST	179.30	−14.51	18.38	−1.30	178.41	−14.89	16.89	−1.41
	TR	181.22	−13.59	18.73	0.57	180.90	−13.71	17.45	1.90

[a] Scenarios are defined as follows: BM = benchmark, ST = storage, TR = transfers.

Future research in this area would seek to incorporate other important benefits associated with the Arkansas River, such as instream flows and recreational uses. More accurate analysis of the economic benefits of transfers relative to storage depends on accurate depictions of production functions, as well as climate conditions and water rights. In addition, complicating hydrology issues such as groundwater pumping and physical limitations in transferring water need to be considered in more detail.

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