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Improving the ability of a water market to efficiently manage drought

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Abstract. Some water markets maintain institutional elements that provide allocative advantages to specified water users. In the Lower Rio Grande Valley, water rights are designated as either municipal or agricultural (irrigation), with certain prioritization advantages afforded to municipal accounts. While sales of rights between municipalities and irrigators are allowed, the priority disparity results in a prohibition on leasing between sectors. Concern over meeting future urban demand has led municipalities to purchase rights well in excess of current needs. The inability to lease municipal water to irrigators removes a significant and growing fraction of available water from the market. The additional flexibility provided by leasing provides a valuable tool for managing seasonal drought. In this analysis the justification for prioritized municipal water is investigated. Results indicate that the added security municipalities may derive from higher prioritization during drought is accompanied by economic inefficiencies in regional water allocation. It is argued that eliminating municipal protection and the consequent allowance of intersectoral leasing would contribute to regional well-being at small cost to municipal water users.

1. Introduction

Recent years have seen water scarcity become a reality in many western states. Much of the west has reached the practical limit of water resource development. Fewer opportunities to increase supply have led to the implementation of alternative water allocation strategies. As a result, a growing number of regions have begun to employ market principles as a way of encouraging more efficient water use.

This work focuses on an analysis of the water market currently operating in the Lower Rio Grande Valley, a four-county area (Starr, Cameron, Willacy, and Hidalgo) in south Texas along the United States–Mexico border (Figure 1). The region supports a thriving agricultural industry, as well as a rapidly growing urban populace. Limited groundwater resources result in the valley's being almost totally dependent on the Falcon/Amistad reservoir system for its water supply [*Texas Natural Resource Conservation Commission* (*TNRCC*), 1994]. Falcon reservoir feeds the Lower Rio Grande, with the Amistad reservoir located some 300 river miles (483 river km) upstream. The combined storage of the two is strictly divided between the United States and Mexico according to international treaties enforced by the International Boundary and Water Commission (IBWC) (R. C. Griffin and J. R. Ellis, unpublished manuscript, 1998).

While the Falcon/Amistad system is often capable of supplying sufficient water to the valley, drought conditions in recent years have severely depleted reservoir storage. In 1996 the reservoir system reached its lowest water level since completion of the Falcon dam in 1954 (International Boundary and Water Commission, unpublished data, 1995). This resulted in a supply of water insufficient to fill the accounts of water rights holders (explanation of this process follows in the next section) in both 1996 and 1997.

Projections indicate that the valley's 1990 population of 700,000 [*U.S. Census Bureau*, 1997] will increase approximately 30% by the year 2000 and by a factor of 3 by the year 2050 [*TNRCC*, 1994]. Irrigated agriculture presently accounts for roughly 85% of total water use; however, the sustained influx of people to the region has encouraged a steady conversion of water rights from irrigation to municipal. While the current water market has presided over a relatively smooth transfer of water, periods of scarcity have exposed potential inefficiencies within the market's structure. Permanent water rights are expensive (\$700–800/acre-foot (\$567–648/1000 m^3)) and the unpredictable nature of drought complicates their valuation. Maintaining an extra allowance of rights for use in drought years is difficult for irrigators who often operate near the margin. Temporary leasing is a relatively inexpensive option (\$10–50/acre-foot (\$8–40/1000 m^3)) that allows for decisions based on more current information. Under present rules, however, intersectoral leasing (leasing between municipalities and irrigators) is prohibited as a result of allocative advantages that

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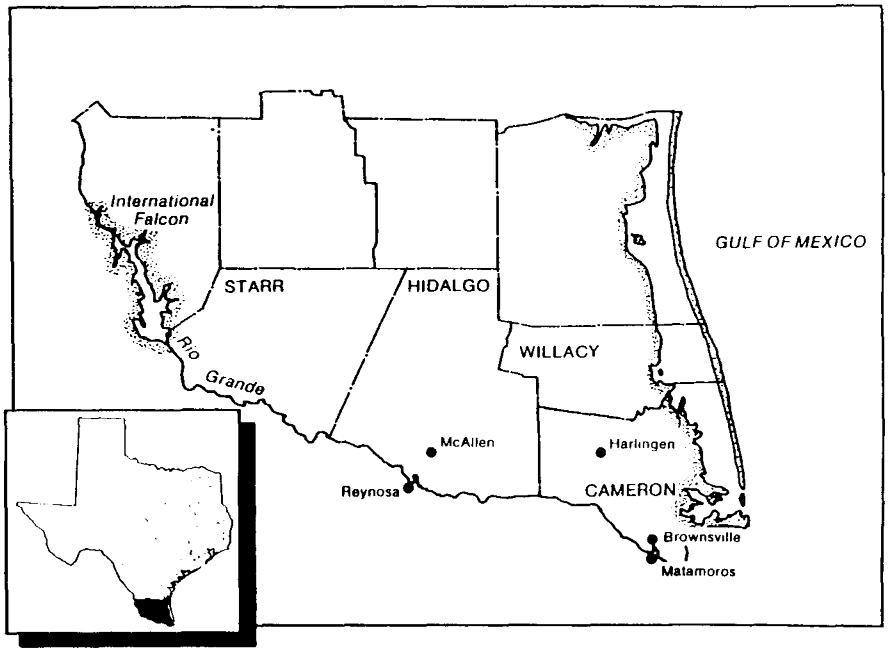

Figure 1. Lower Rio Grande Valley [*Chang and Griffin*, 1992].

guarantee urban water supplies. Continued population growth will increase regional water demand and the frequency and nature of shortfalls, exacerbating the consequences of market inefficiencies. These considerations suggest an exploration of methods to improve the efficiency of water allocation during drought.

Similar to many other rapidly growing regions in the western United States, the degree of efficiency with which the valley's limited water resources are utilized will play a major role in determining the level of regional growth that can be sustained. Urban-agricultural conflicts over water allocation have become commonplace throughout the western states, and increasing municipal demand will provide additional challenges to policy makers. One of the first considerations in any such policy debate is the welfare of urban water users. Not far behind is consideration of market style reforms. These results should prove useful to decision makers considering such policies.

2. Water Market

2.1. Economic Efficiency

The difficulties associated with monitoring consumptive and nonconsumptive uses of water can jeopardize the establishment of a well-functioning water market. In the Lower Rio Grande, however, several factors contribute to reducing concern over this issue. The valley's combination of arid soils and a land surface which slopes away from the river acts to minimize return flows to the Lower Rio Grande [*TNRCC*, 1994; *Schmandt and Mu*, 1992; *Chang and Griffin*, 1992]. These conditions allow water diverted from the river to be considered as entirely consumed. Consequently, there are relatively few opportunities for a transfer of rights to adversely affect third parties, except for those effects transmitted as secondary economic effects (a pecuniary externality). The physical location of the majority of diversions in the valley also contributes to lessening concerns over third-party effects. This applies to both rights transfers and issues of instream value. Most diversions take place in a concentrated area of the valley which lies considerably downstream of the Falcon dam and near to the Gulf of Mexico. Because most transfers take place between users in the same general location, and because these diversions take place after the water has traversed most of the valley, worries over the maintenance of instream flows have been minimal. The valley's characteristics have lessened fears over third-party effects to the extent that the public notice requirement, mandated in other watersheds prior to approval of water rights transfers, has been eliminated.

2.2. History and Administration

Years of contentious legal wrangling over water ownership in the Lower Rio Grande Valley came to an end in 1971 with the finalizing of a state court adjudication of regional water rights. Those people determined by the court to have claim to waters of the Rio Grande and the Falcon/Amistad reservoir system were awarded a right to divert water. Irrigation rights were distributed in proportion to the amount of land that claimants had historically used for irrigated activities. A separate designation was made for municipal rights. These were granted to the various cities and townships throughout the valley and were also based on historical use patterns. During this initial allocation, municipal accounts were granted some additional rights to allow for future growth.

Administering the accounts, withdrawals, and transfers of water within the Valley is the responsibility of the Rio Grande Watermaster's office, a division of the Texas Natural Resource Conservation Commission (TNRCC). In order to divert water, a rights holder in the valley must contact the Watermaster's office to request a release from Falcon reservoir. The appropriate amount is then deducted from the respective account. Most rights holders must wait before drawing the requested water to account for travel time from the dam to the point of diversion (from 1 to 5 days depending on location). Diversions are then transported to the point of use through a system of canals and pipelines. Pumping and conveyance of water is

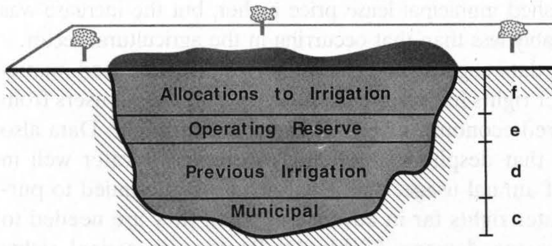

Figure 2. Allocations in the Falcon/Amistad reservoir system.

often done by the valley's 29 irrigation districts, pseudogovernmental bodies which oversee the distribution of water to members within their jurisdictions.

2.3. Sales and Leasing

The 1971 adjudication made provisions for the buying, selling, and leasing of water rights. Each water right is designated for use in either municipal or irrigation activities. Water rights can be bought or sold both within and between the two sectors. The latter transaction, however, requires that a change of use petition be filed with state authorities, initiating what is usually a quick approval process within the valley. As legal requirements are slight and no transfer fee is assessed, the transaction costs of such an action are relatively low. Additionally, while the watermaster's office takes no active role in transfers, it does facilitate the process by maintaining an updated list of parties interested in buying, selling, or leasing rights. A copy of this list can be obtained with a phone call.

All transactions must be registered with the watermaster, and while sales require a permanent signing over of the rights, leasing agreements can simply be phoned in. Leases or "contracts" result in the movement of water from one account to another. These transfers are temporary and do not constitute a permanent transfer of water rights. The lessee has year from the date of the transaction to use the water or it reverts to general reservoir storage. As with the sale of water rights, a list of parties interested in leasing water is maintained by the watermaster and can be obtained with a phone call. This convenient medium for exchange, coupled with the absence of any transfer fee, keeps the transaction costs of leasing to a minimum.

While leasing is allowed within the respective sectors, leasing between the two sectors is forbidden. The reasons for this derive from the rules used to distribute available reservoir storage. The distribution protocol, for reasons to be discussed shortly, favors municipal water users. As a result, the originators of the system determined that it would be unfair to allow municipalities to profit from the advantage by leasing water to irrigators during periods of scarcity.

2.4. Current Operating Rules

Water is distributed to rights holders accounts according to the procedure described by the *Texas Water Commission* (*TWC*) [1987]. Allocations are based on the available storage in the reservoirs and are performed on a monthly basis as needed to account for new inflows. (Total storage in the Falcon/Amistad system is represented as a single reservoir in Figure 2. Distributions are not to scale.)

2.4.1. Step a. The total volume of U.S. storage held in the Falcon/Amistad system is determined by the International Boundary and Water Commission.

2.4.2. Step b. From total volume, a portion is removed from consideration as dead storage. This volume (4600 acre-feet (5.7×10^6 m^3)) represents the amount of reservoir storage which lies below the drawpoint of the dam, or is otherwise unreachable in the system. Dead storage volume is too small to be represented in Figure 2.

2.4.3. Step c. A volume is allocated with the intent of providing enough water to completely meet municipal water requests if they were to fully exercise all of their rights. Presently, this reserve is set to a level of 225,000 acre-feet (2.78×10^8 m^3). Its size is increased periodically to keep pace with the growing number of municipal rights. The most recent adjustment (1986) increased the reserve's volume from 125,000 acre-feet (1.54×10^8 m^3). Since 1986, actual municipal water usage has grown from 150,000 acre-feet (1.85×10^8 m^3) to a level of 190,000 acre-feet (2.34×10^8 m^3) (1995). Approximately 80% of this water is used by cities in the lower valley; the remaining 20% is diverted in the Middle Rio Grande, above Falcon reservoir.

2.4.4. Step d. The volume of water previously allocated to irrigation accounts is maintained. While under extreme drought conditions irrigators can have water deducted from their accounts (a "negative" allocation to which municipal accounts are immune), water already assigned to an account is generally safe from seizure.

2.4.5. Step e. An operating reserve, whose size varies as a percentage of overall reservoir storage (11.4%), is deducted to account for losses due to evaporation, seepage, and instream conveyance losses (but only losses which occur within the banks of the Rio Grande). This volume is also intended to act as an "emergency" reserve. Although the reserve's size varies with storage, it is required to remain above 275,000 acre-feet (3.39×10^8 m^3).

2.4.6. Step f. Reservoir storage remaining after deducting the sum of steps b–f from total storage in step a is allocated to irrigation rights holders on a pro rata basis.

Within the present set of rules, irrigators must shoulder the majority of adverse impacts during drought. The municipal reserve remains constant throughout the year, regardless of how much water has been withdrawn from municipal accounts. For example, while municipal users may have diverted 100,000 acre-feet (1.23×10^8 m^3) of water by July, the volume of the municipal reserve will still remain at 225,000 acre-feet (2.78×10^8 m^3) when allocations are made at the end of the month. This is a matter of increasing concern considering that municipalities do not even make use of their full complement of authorized water (Table 1). These advantages in the allocation process act to economically insulate municipalities from the market effects of water scarcity.

One of the consequences of this practice can be seen by inspecting water lease prices within the respective sectors during a drought. Figure 3 contains a normalization of the weighted average monthly lease price (Rio Grande Watermaster's office, unpublished data, 1997) during the years 1994–1997. Data have been normalized by the weighted average lease price prevailing during 1994, before the impacts of the current drought began to take hold. Analysis of normalized data is more appropriate given the inherently different incentive structures experienced by farmers and municipal utility managers, as well as their respective ability to pay. While most farmers are engaged in private enterprise and may be considered profit maximizers, incentives for municipal managers are less tightly linked to profit and more often to the maintenance

Table 1. Municipal Water Allocation, Rights and Use, 1985–1995

Year	Total Municipal Rights*	Municipal Allocation*	Municipal Usage*	(Allocation Minus Usage)
1985	221,946	125,000	152,708	−32,708
1986		225,000	159,910	65,090
1987		225,000	159,831	65,169
1988		225,000	165,309	59,691
1989		225,000	190,031	34,969
1990	246,964	225,000	181,465	43,535
1991		225,000	181,240	43,760
1992		225,000	174,502	50,498
1993		225,000	183,124	41,876
1994		225,000	186,829	38,171
1995	313,497	225,000	192,112	32,888

Data are in acre-feet (1 acre-foot equals 1234 m^3). Source is Rio Grande Watermaster's Office (unpublished data, 1996).
*Includes municipal of the Middle and Lower Rio Grande.

of a steady supply of water. This likely results in more risk averse behavior which, when combined with the improved ability to pay exhibited by most municipalities, would contribute to the higher lease prices experienced in the municipal sector during years in which water is relatively plentiful.

The years 1994–1997 saw a gradual worsening of the drought which has affected the region to varying degrees since the early 1990s. The most illustrative indication of increasing water scarcity in the region is storage in the Falcon/Amistad system, essentially the valley's sole water supply. As reservoir storage approached record lows in the summer of 1996, the lease price for irrigation water rose sharply and remained relatively high throughout the balance of the year and into 1997.

In contrast, the lease price for municipal water displayed less volatility and remained well below irrigation lease prices (in both real and normalized terms) throughout much of 1996 and 1997. In addition, the lack of any leasing activity within the municipal sector during a number of months in the early stages of the drought (denoted by the absence of a symbol) provide a further indication that municipalities felt fewer impacts from increasing scarcity. As the drought persisted, shortages in several

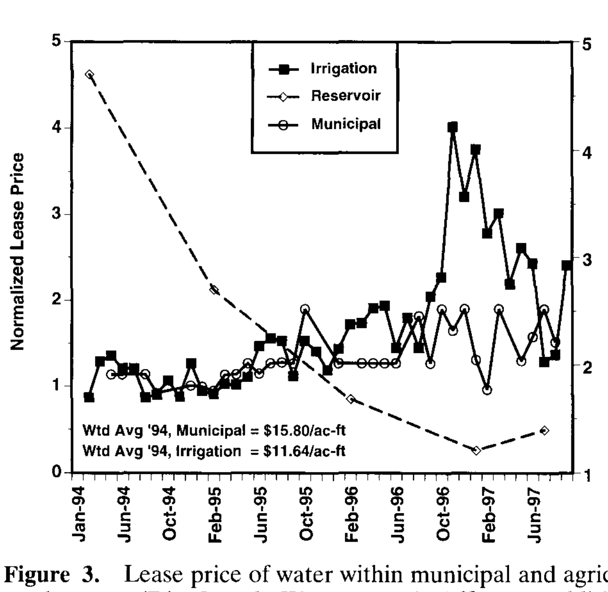

Figure 3. Lease price of water within municipal and agricultural sectors (Rio Grande Watermaster's Office, unpublished data, 1997).

cities pushed municipal lease price higher, but the increase was considerably less than that occurring in the agricultural sector.

These data suggest that the higher priority assigned municipal water rights has essentially protected municipal users from the desired economic effects of the recent drought. Data also indicate that despite maintaining a reserve of water well in excess of annual usage, municipalities have continued to purchase water rights far in advance of when they are needed to meet growing demand (Table 1). Because municipal rights have elevated seniority and intersectoral leasing is consequently prohibited, this excess capacity can remain unused for as long as 10 years.

As the fraction of municipal water increases, justification for the municipal priority should be reassessed. If municipalities are unable to compete effectively in a water market, then municipal allocative advantages may be appropriate on the basis of social welfare concerns. Conventional wisdom indicates that municipal water is generally valued at a higher level than irrigation water and that municipalities should have few problems bidding for water effectively. This reasoning does not, however, describe the magnitude of the price increase which might be experienced by municipal users in an open market. Assessing the magnitude of such a price increase would provide information valuable in evaluating the implications of removing the municipal priority.

3. Methodology

A model is developed to estimate the price increase which would be experienced by municipal users under varying degrees of scarcity in a competitive market. Model results are designed to evaluate the allocation which would maximize the regional net benefits which the valley derives from the use of its water supply. This is accomplished within a framework of static efficiency.

The cycle of water use in the region is annual, with the majority of water use taking place in the spring and summer [*IBWC*, 1995] and the majority of annual rainfall coming between August and the end of the year [*U.S. Geological Survey* (*USGS*), 1997]. The unpredictability of drought greatly inhibits the ability of rights holders to make informed decisions on whether to use water or conserve it for future use. This leads to rights holders basing most water use decisions on yearly needs and thus the discretization of water use into annual periods. Therefore all references to efficiency in this work will represent the static case.

The optimization routine is formulated to include water demand, water delivery costs, and conveyance losses observed within both the agricultural and municipal sectors. The normative results determine the water allocation pattern maximizing regional net benefits without regard to distributional effects. While several functional forms were considered, the Cobb-Douglas form is adopted for use here. The model maximizes aggregate consumer and producer surplus experienced across five sectors. Two of these sectors are municipal, and the remaining three are agricultural. Combined, these sectors account for approximately 99% of water use in the region. The selection of these sectors permits the separation of small and large municipalities and the partitioning of irrigated agriculture into more homogeneous classifications. Irrigated sectors are field crops, vegetables, and citrus. Maximization is constrained by the raw water supply, which is varied across historical levels. The model endogenizes differential sectoral char-

Table 2. Model Parameters

		Demand Point			Loss Fraction (L_i)		
i	Activity	Quantity (Q_i), acre-feet	Price (P), dollars/acre-foot	Elasticity (ε_i)	River–Plant	Plant–Tap	River–Field
			Municipal Sectors				
1	30,000	45,000	16.00	−0.32	0.20	0.30	
2	>30,000	95,000	16.00	−0.32	0.10	0.15	
	subtotal	140,000					
			Agricultural Sectors				
3	field crops	547,500	16.00	−0.70			0.20
4	vegetables	371,900	16.00	−0.40			0.20
5	citrus	227,500	16.00	−0.40			0.20
	subtotal	1,146,900					

1 acre-foot equals 1234 m^3.

acteristics such as demand elasticities, conveyance losses, and water delivery costs (Table 2). The general model is

$$\operatorname*{Max}_{\mathbf{Q}} \sum_{i=1}^{5} \mathrm{NB}_i(Q_i) \qquad \text{subject to} \sum_{i=1}^{5} Q_i \le \bar{Q},$$

where $\mathbf{Q}$ is a vector of the five control variables (Rio Grande diversions for all five sectors); NB_i are the functionals relating economic surplus to water diversions; and $\bar{Q}$ is available diversion water from the Rio Grande.

The optimization problem becomes fully specified with knowledge of Cobb-Douglas demands for processed and delivered water for each sector; sectoral loss ratios, $L_i \in [0, 1]$, relating delivered water (q_i) to raw water (Q_i); and cost functions for performing processing and delivery services. The delivered water demand functions, $q_i = A_i P^{\varepsilon_i}$, are each parameterized by two scalars, A_i and ε_i. The relationships between delivered water and diverted water are given by $q_i = (1 - L_i)Q_i$. The cost functions used in this analysis presume constant average costs: $\mathrm{Cost}_i = C_i q_i$. Once these details are employed to compute sectoral surpluses by integration, the individual net benefit functions become

$$\mathrm{NB}_i(Q_i) = A_i^{-1/\varepsilon_i} \frac{\varepsilon_i}{\varepsilon_i + 1} ((1 - L_i)Q_i)^{(\varepsilon_i+1)/\varepsilon_i} - C_i(1 - L_i)Q_i.$$

3.1. Municipal Demand

Determination of the municipal water demand function for the Rio Grande Valley is based on research by *Griffin and Chang* [1989]. Their cross-sectional study of community water demand surveys the monthly water use and pricing rates of 221 communities throughout Texas (including seven in the valley) over a 5-year period. The 12,000+ price/usage observations were statistically regressed with data on area climate, rainfall, and per capita income, among others. The parameter extracted from this work is the price elasticity of per capita, daily water demand, as measured leaving the treatment plant. The elasticity reported (−0.32) agrees quite well with determinations made in other municipal demand studies [*Wong*, 1972; *Foster and Beattie*, 1979; *Danielson*, 1979]. This elasticity is used in conjunction with the prevailing price for water delivery (P) and typical values for delivered water (q_i) from the years 1993–1995, to derive the constant (A_i) required to fully specify the Cobb-Douglas demand function (Table 2).

The relatively small area of the valley combined with the homogeneity of its municipalities in terms of the relevant parameters [*USGS*, 1997; *U.S. Census Bureau*, 1997] allows for the measure of daily per capita water consumption to be expanded over the entire municipal population. This value is then converted to a regional annual demand function for treated water leaving the plant.

3.2. Agricultural Demand

The demand function for irrigation water is formulated based on information from previous studies, region specific farm data, and crop budgets. Price elasticities were adopted from a study of derived demand in the Lower Rio Grande Valley [*Gray and Trock*, 1971]. The age of the study presents some concern. However, a comparative investigation of present water-related practices in the valley versus those typical during the early 1970s yielded a great degree of similarity. Cropping patterns, farming techniques [*Texas Agricultural Extension Service* (*TAES*), 1972, 1973, 1990–1996], and methods of water conveyance and application [*Texas Water Development Board* (*TWDB*), 1996b] in the region are relatively unchanged over the period in question. In addition, with the exception of cotton, estimates of per acre yield for the various crops has remained virtually identical [*TAES*, 1972, 1973, 1990–1996]. Some concern exists over the relative price changes in the respective crops, but these discrepancies have not been determined to be sufficient to invalidate the results. Therefore the adoption of price elasticity information from the work is deemed appropriate. Irrigation water demand for the three crop types (field, vegetable, and citrus) exhibits behavior described by elasticities of −0.7, −0.4, and −0.4, respectively (Table 2). All elasticities fall well within the range defined in the literature for western irrigation water demand [*Moore and Hedges*, 1963; *Kulshreshtha and Tewari*, 1991; *Shumway*, 1973]. These elasticities are combined with current data on irrigation water use in the Valley [*TWDB*, 1996a], information on crop acreage [*Texas Agricultural Statistics Service* (*TASS*) 1994], and individual crop water requirements [*TAES*, 1972, 1973, 1990–1996] to establish the amounts of water delivered for use (q_i) for each respective crop type. Irrigation demand functions for each crop type are formulated following the procedure outlined in the previous section.

One aspect of the demand functions which should be noted applies specifically to the irrigation of field crops. Field crops in the valley produce a higher yield when irrigated but, unlike the more water intensive vegetable and citrus crops, can also be grown dryland. Given the relatively low profitability of field crop production and the important role of water costs in influencing total production costs, there may be a "choke price"

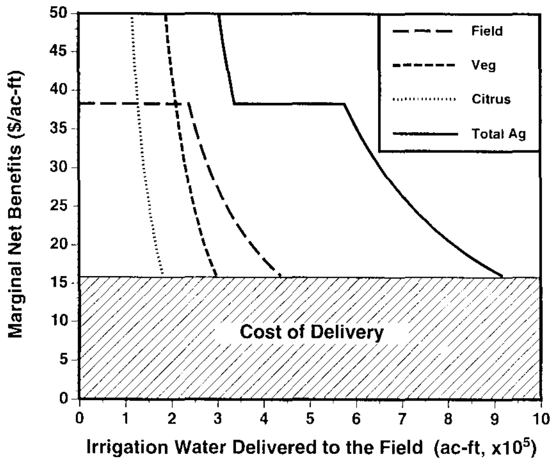

Figure 4. Demand for water by the three irrigation types.

above which demand is nonexistent. This results in a perfectly elastic region for field crop irrigation demand, indicating that the activity either ceases entirely or converts to dryland operation. Such a choke price likely exists for vegetable and citrus irrigation water as well, but at prices outside the range likely to occur given historical levels of regional water supply. The effect of a field crop irrigation choke price is apparent in the shape of the combined regional irrigation demand function (Figure 4). Such behavior, and the resulting shape, are consistent with a number of other studies analyzing regional irrigation water demand [*Moore and Hedges*, 1963; *Sun*, 1972; *Gisser*, 1970; *Kelso et al.*, 1973; *Hooker and Alexander*, 1998]. Determination of the choke price for field crops is made from budget information on the major field crops [*TAES*, 1972, 1973, 1990–1996]. These crops combine to account for over 60% of irrigated farm acreage and an estimated 50% of agricultural water use [*TWDB*, 1996b; *TASS*, 1994]. Budget estimates indicate that for the years 1990–1996, the highest value derived from irrigation of any of the three field crops over that period was approximately $38.23/acre-foot ($30.98/1000 m^3) (exclusive of delivery costs). Given that this value is the maximum derived value for water in these enterprises, and that in most years this value is considerably less, it is likely that increasing water price to this level would render the irrigation of field crops unprofitable and drive these farming operations to dryland.

3.3. Adjusting for Raw Water Demand

It is also important to point out that the total regional demand function is in terms of raw, untreated, river water delivered to the field. This is in contrast to the municipal demand function, which is placed in terms of treated water leaving the plant. Putting both municipal and agricultural water demand into a comparable form requires that both be traced back to a common point of reference. In this case the point of diversion from the river has been chosen. Selecting the river as a reference point is also useful because it is the right to divert raw water at the river which is bought, sold, or leased in the valley's water market. Conveyance losses occurring between the point of diversion and the point of use have an effect on the marginal net benefits accruing to users in the respective sectors. As the objective of the modeling effort is to estimate the price increase experienced by municipal users when in competition with irrigators for scarce water, comparability of the functions is paramount.

Water conveyance from the river to the field is usually carried out by pumping water through a series of open, earthen canals. The majority of pumping is performed by irrigation districts, of which there are 29 of varying size across the valley. Many districts attach a loss factor to water requests which ranges from 15% to 35% and is designed to account for seepage, evaporation, and the end of system overflows necessary to pump water to the far reaches of the distribution network.

Irrigation districts are also responsible for first stage delivery of a considerable fraction of the valley's municipal water. The mode of delivery from the river to the treatment plant is usually pumping through either pipes or canals. Some cities located on or near the banks of the Rio Grande pump water directly from the river into the plant. As a result of the increased use of pipe, the conveyance losses associated with municipal deliveries to the plant are often less than those incurred in delivery to the field. Transport loss ratios employed in the analysis are reported in Table 2.

4. Results and Discussion

Figure 5 illustrates the valley's total municipal and agricultural demand for river water at the point of diversion from the river (after removal of delivery costs). This function represents the allocation which maximizes regional net benefits as determined using the previously described methodology and the parameters described in Table 2. The left-hand axis indicates the value of raw river water at the point of diversion. This represents the shadow price for water that one would consider when making decisions on whether to lease. While this is a suitable metric for evaluating agricultural prices, it is more illustrative to view municipal demand in terms of cost at the tap. The right-hand axis represents the price increase at the tap (over and above existing price) that users in the smaller municipalities would experience if the opportunity cost of water were passed directly onto them. This price incorporates the losses sustained as a result of conveyance from the river to the treatment plant, as well as those incurred between the plant and the tap. Due to the lower conveyance losses experienced during distribution in the larger municipalities, users in these areas would experience even lower price increases.

Table 3 contains optimization results for a range of possible regional water supply levels. When water supply is 1,286,000 acre-feet (1.587×10^9 m^3) or higher, river water is not economically scarce, and it has a zero opportunity cost. Under these conditions, equilibrium lease prices are $0 for river water, and there is no need for municipal rates to incorporate water scarcity values. As the regional water supply falls, the value of raw water increases as indicated within Table 3. Also tabulated is the consequent rate implications for clients of small municipalities.

In the case of a very serious drought lowering water supply to approximately 828,000 acre-feet (1.02×10^9 m^3), the marginal net benefit of water rises to $17.79, which is the field crop choke price after accounting for conveyance losses and delivery costs. Even at this elevated level of water scarcity, the inclusion of water shadow price adds but $0.10 per 1000 gallons ($0.026 per 1000 L) to small municipality water rates. For the typical household consuming 10,000–12,000 gallons per month (3.8×10^4 to 4.5×10^4 L per month), the residential water bill would increase $1 or $2 per month. Rate and bill increases would be lower in large municipalities.

At more severely curtailed supply levels than those pre-

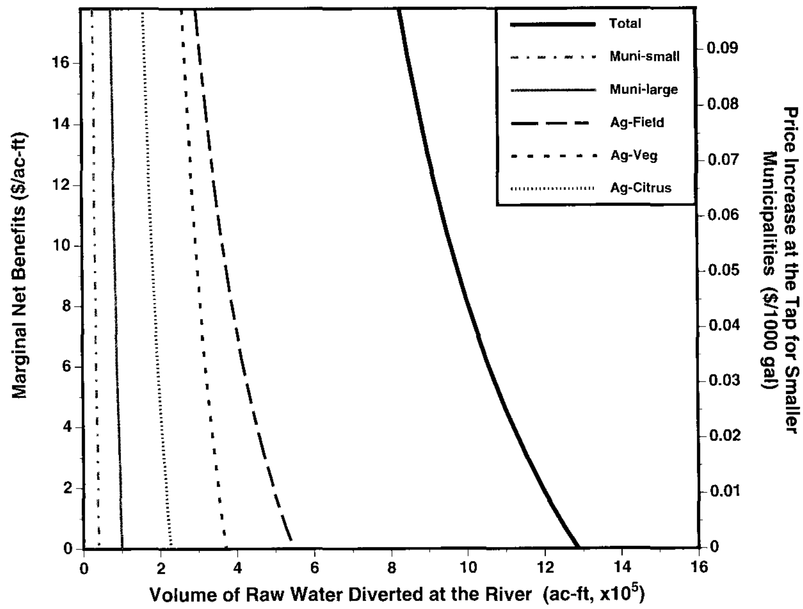

Figure 5. Sectoral net benefits.

sented in Table 3, field crop irrigators would optimally pursue dryland production. They could not economically justify water purchases at these valuations, and they could more profitably lease any water they own.

As a worst case scenario, model parameters can be modified to represent a drought scenario which would be very unfavorable to holding down municipal water prices. If the available annual water supply dropped to 600,000 acre-feet (7.40×10^8 m^3) (over 250,000 acre-feet (3.08×10^8 m^3) below the lowest annual reservoir yield of U.S. water since the Falcon/Amistad system was completed in 1972 [*Schmandt and Mu*, 1992; *IBWC*, 1995]), the elasticity of water demand for field crop irrigation (the model's most sensitive parameter) were set to a relatively inelastic −0.5, and, finally, the choke price for field crop irrigation were disregarded, the shadow price of river water (after the inclusion of delivery cost and conveyance loss considerations) rises to $38/acre-foot ($30.79/1000 m^3). If this higher price is passed on directly to municipal users, it translates to an increase of $0.25/1000 gallons ($0.066/1000 L) ($2–3 per month) for the average household in the smaller municipalities. This amount seems unlikely to subject municipal users to an unreasonable financial burden, particularly in the face of the crisis that the community as a whole would be experiencing if water availability were to drop to these levels.

On the basis of these results, it seems apparent that under open market conditions, municipal users would not require advantages in the allocation process to secure the volumes of water necessary to sustain them. Furthermore, considering the relative invariance of municipal water demand and the fairly typical crop mix in the valley (a combination of more water intensive fruits and vegetables and less water intensive field crops), these results indicate that a higher municipal priority is unlikely to be justified in many regional scenarios. Given that municipalities appear to be entirely capable of competing for water in the lease market, an analysis of the efficiency improvements which might be realized by eliminating municipal allocative advantages is also undertaken.

The degree of water conservation encouraged in municipal

Table 3. Optimal Allocations of Raw River Water Under Alternative Supplies

Total Supply, 10^3 acre-feet	Marginal NB, dollars/acre-foot	Municipal Price Rise, dollars/1000 gallons	Municipal Allocations, 10^3 acre-feet		Agricultural Allocations, 10^3 acre-feet		
			Small	Large	Field	Vegetable	Citrus
828*	17.79	0.10	30.3	77.3	297.5	262.4	160.5
850	16.23	0.09	30.8	78.5	308.7	268.0	164.0
900	13.08	0.07	31.9	81.3	334.5	280.6	171.7
950	10.43	0.06	33.1	84.0	360.7	293.0	179.2
1000	8.18	0.05	34.1	86.6	387.4	305.2	186.7
1050	6.25	0.03	35.2	89.1	414.4	317.2	194.0
1100	4.58	0.03	36.3	91.5	441.9	329.0	201.3
1150	3.13	0.02	37.3	93.9	469.7	340.7	208.4
1200	1.86	0.01	38.3	96.2	497.8	352.2	215.5
1250	0.74	0.00	39.3	98.4	526.3	363.6	222.4
1286	0.00	0.00	40.0	100.0	547.5	371.9	227.5

NB denotes net benefit. 1 acre-foot equals 1234 m^3; 1 gallon equals 3.785 L.
*Supply below which field crop irrigation choke price is exceeded.

consumers as a result of any price increase arising from removal of municipal advantages would be small given the presumed demand elasticity. Of more significance is the perpetual reserve of municipal water to which the allocative advantages entitle them. Since 1986, when the size of the reserve was increased to account for municipal rights purchases (from 125,000 to 225,000 acre-feet (1.54–2.78 × 10^8 m^3)), a considerable volume of water has been placed beyond the reach of irrigators (Table 1). The continued purchase of water by municipalities has, once again, pushed the number of municipal rights well beyond the current size of the reserve. Municipal users held approximately 312,000 acre-feet (3.85 × 10^8 m^3) of rights in 1995 (Rio Grande Watermaster's office, unpublished data, 1996). If state authorities follow precedent and increase the reserve's size to a level equivalent with present rights, as has been done historically, the gap between annual municipal use and their allocation would be 120,000–130,000 acre-feet (1.48–1.60 × 10^8 m^3). The trend among municipalities of staying well ahead of growing demand in their acquisition of water rights will become even more problematic as population continues to grow.

Interviews with the Rio Grande Watermaster indicate that increasing the size of the municipal reserve is an issue which will soon be up for review (C. Martinez, Rio Grande Watermaster, personal communication, 1997), and there is no evidence that any consideration has been given to deviating from past practices. In coming years, as the valley's populace climbs toward projected levels, continuing to follow these guidelines may result in over 200,000 acre-feet (2.47 × 10^8 m^3) of water lying unused in the reservoirs during periods of drought. While this water is not wasted, as it is used to maintain municipal accounts in later years, the large volume of protected water could be very effective in lessening the impacts of droughts like the one in which the valley is presently mired. Removing the allocative advantages afforded to municipalities would bring this water back into the market by removing the rationale for prohibiting intersectoral leasing, thereby allowing the valley's cities to lease water to irrigators. This change would not require that municipalities give up any of their rights. The additional water would simply be made available for voluntary intersectoral leasing transactions.

This raises the point that if the water were to be made available, would municipalities lease it? Municipal utilities are notoriously risk averse, as can be seen in their efforts to stay well ahead of demand in their acquisition of water rights. Valley cities had more than sufficient water rights to support 1995 municipal demand in the early 1980s, yet still continued to buy. What seems to drive these acquisitions is concern over future, not current, shortages. At any point in time, most of the region's municipalities are well aware that they have more than enough water to meet demand. The fact that municipal demand is relatively predictable, generally deviating by less than 5% from year to year, further eases municipal fears of an unexpected shortfall. While it is true that should the municipal priority be removed, cities could face years in which they would receive only a pro rata share of their total rights, they presently use only 60% of the total water to which they are entitled. Another concern in eliminating the reserve might be that risk averse behavior would lead municipalities to acquire water rights at an even faster pace. This would present few problems as intersectoral leasing would be allowed, and the water would still remain available within the market. Municipal utilities often invest considerable funds to obtain water rights that will not likely be put to use for 10 years or more. The opportunity to recoup some of their initial investment through leasing would provide an attractive option to many.

Evidence of the municipalities' willingness to become involved in water-related transactions has been seen during the drought years of 1994–1997. Instances of municipalities leasing to agriculture, in violation of state agency rules, have not been uncommon. In addition, some irrigation districts have sold water rights to municipalities at reduced rates, on condition that the districts be allowed to maintain the rights as agricultural until such time as the city requires them. While such contingent transactions are not explicitly provided for in the rules of operation for the Rio Grande [*TWC*, 1987], their legality has yet to be challenged. Maneuvering of this nature is generally an indication that problems exist within a market, as individuals work outside the system to satisfy their requirements.

This combination of factors considerably weakens the case for maintaining a higher municipal priority, but securing municipal water supplies is still a politically and emotionally charged issue. It was the shortages experienced by municipalities during the drought of the 1950s which led to rules favorable to municipalities being made part of the original adjudication governing the operation of the Rio Grande. These rules overlook the fact that municipalities have several options in the absence of these advantages, were they to find themselves running short of water.

The primary option would be to buy or lease the necessary water on the open market. A lease price offer of $20/acre-foot ($16.20/1000 m^3) would provide many irrigators with a higher return than they would realize irrigating their crops, and the cost of procurement could be passed along to municipal consumers for literally pennies. This would represent an equitable arrangement by most standards, and one that is very unlikely to deprive municipal users of water which they would require for activities deemed to have high welfare value. Water for drinking, cooking, bathing, and sewerage often make up less than 40% of municipal water use [*Tchobanoglous and Schroeder*, 1987]. In addition, it should be remembered that reservoir allocation procedures already provide for a general reserve, not to fall below 275,000 acre-feet (3.39 × 10^8 m^3). This reserve acts not only to counteract seepage and evaporative losses, but also as emergency storage which could be allocated if conditions should warrant.

A final point involves the market participation of the irrigation districts in the valley. The districts control much of the valley's water, as well as its distribution. Water distributed to individuals within a district is often held in trust by the districts themselves. This arrangement could lead to some intransigence on the part of the districts in leasing water back to municipalities. Difficulties in distributing the proceeds of leases to members of the districts, in addition to apportioning the lesser volume available, would have to be resolved. However, issues are simplified considerably by the realization that the leasing of water would most often be in the opposite direction, from municipalities to agriculture. Municipalities continue to acquire water rights, and thus reserve water, at a pace which far outstrips their growth. A modification to the present allocation system which brings more of that water back into the market, rather than leaving it in the reservoir during periods of scarcity, would represent an improvement in the region's ability to manage drought.

5. Conclusions

Under ideal market conditions, the higher priority attached to municipal rights is not economically justified. Results from an optimization model of regional net benefits support such a conclusion. In addition, any reasonable variation of these parameters does not result in water costs above that which municipalities and municipal users could assume with little detrimental effect. Even under a "worst case" scenario, results indicate that municipalities would be capable of effectively bidding for water without jeopardizing municipal users' ability to satisfy important health and welfare needs. In the Lower Rio Grande the existence of supplementary safeguards already provided for in the system (the unallocated "emergency" reserve) further weakens arguments for maintaining the allocative advantages afforded municipalities.

Removal of these advantages from the rules of operation would have two important consequences. First, it would bring a volume of water which was previously unavailable back into the market during periods of drought. If the current system remains unchanged and population growth continues, the gap between actual municipal water use and the size of the untouchable municipal reserve could grow to as much as 200,000 acre-feet (2.47×10^8 m^3). Second, eliminating the municipal priority would allow leasing of water between municipalities and irrigators. This would allow irrigators to temporarily increase their water usage during scarce years. The reentry of this water into the market could have a marked effect in reducing the agricultural losses sustained during drought. This is significant as it is these periods which inflict the most serious, and sometimes irreparable, damage to regional economies. Such changes would also allow municipalities to benefit from their excess water rights through leasing transactions.

The prohibition on intersectoral water leasing effectively handcuffs the market's ability to efficiently adapt during drought. Eliminating the distinction between rights will allow for leasing between all market participants and provide the system with increased responsiveness when reacting to conditions of water scarcity. Such changes in policy will aid in providing a framework for water use which lessens the economic impact of drought on the Lower Rio Grande Valley.

Notation

- A_i water demand parameter for sector i, acre-feet yr^{-1} dollar^{-1}.
- C_i average cost of water for sector i, dollars/acre-foot.
- cost_i total cost of water for sector i, dollars.
- ε_i price elasticity of demand of water demand of sector i.
- i sector designation ($i = 1, 2, \cdots, 5$): 1, Small municipalities, $\leq$30,000 people; 2, large municipalities, $>$30,000 people; 3, agriculture, field crops; 4, agriculture, vegetables; 5, agriculture, citrus.
- L_i fraction of water lost during conveyance for sector i.
- NB_i net benefit function for sector i, dollars.
- P price of water, dollars/acre-foot.
- $\mathbf{Q}$ vector of five control variables.
- $\bar{Q}$ water available for diversion from the Rio Grande acre-feet/yr.
- Q_i water diverted from the Rio Grande for sector i, acre-feet/yr.
- q_i water delivered to fields/treatment plants of sector i, acre-feet/yr.

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