WATER RESOURCES BULLETIN
VOL. 26, NO. 2 AMERICAN WATER RESOURCES ASSOCIATION APRIL 1990

# VALUING URBAN WATER ACQUISITIONS[1]

*Ronald C. Griffin*[2]

ABSTRACT: Municipalities typically seek additional water supplies whenever prospective population and economic growth suggests the inadequacy of currently available water supply. The benefit of supply enhancement is usually construed as avoiding debilitating water scarcity. A more effective approach to planning is to compare the benefits and costs of supply augmentation. The net present value of benefits for a supply increase in a representative Texas community is calculated for alternative scenarios relating to population growth, rate growth, and the temporal distribution of the increased supply. Consumer surplus measures are sensitive to all three of these factors and vary from $0 to over $4000 per acre-foot. A notable finding is that the added supply may offer zero values in cases where real water prices increase at an annualized rate of 4 percent (or greater) which is half the rate occurring in Texas from 1981-1985.

(KEY TERMS: water rates; supply valuation; water marketing; benefit/cost analysis; consumer surplus.)

## INTRODUCTION

Employing either new laws or revised administrative procedures, several Western states have recently enhanced the role of water markets in allocating water resources. Increased reliance upon price-guided allocation institutions (i.e., the various water marketing forms) lifts curiosities concerning the prospective value of water to transactors. Potential buyers wonder what they must pay. Sellers wonder how much can be charged. Previous local transactions or, if necessary, transactions in similar regions can serve as a guide to equilibrium price. Based on reported transactions, municipalities dominate all other buyers in terms of the amount of water purchased, and irrigators or irrigation districts are the usual sellers (*Water Market Update*). Water right purchase prices are ranging from $418 to $675 per acre-foot in Texas. These exchange prices are higher than agricultural water values and presumably lower than municipal water values. Agricultural value is known to be low, generally much less than $100 per acre-foot (Gibbons, 1986; Young *et al.*, 1988). Published evidence concerning municipal value is relatively unavailable. The market-assigned values serve as an interesting departure point for evaluating municipal water value.

Technically sound studies of municipal water value can assist planners in managing their water acquisition policies to the greatest benefit to consumers. The practice of municipal water evaluation is methodologically lucid, so other reasons must be forwarded for the paucity of studies examining municipal water value. One alternative is that the value of municipal water varies greatly with the setting and cannot be generalized. A more plausible explanation is that municipalities do not extend their considerations to prospective value but are merely searching for least-cost options to increase supply (i.e., they are not interested in value or do not possess the means to evaluate value). It should be recognized that heightened water scarcity and the accompanying increased supply costs promises to continually raise real water rates. Consumers will respond with conservation activities, but water bills will still increase due to the low price elasticity of demand. As a result, potential rate increases driven by prospective water development and infrastructure expansion will be viewed more skeptically and considered more carefully. Consumers will urge for water development which *has been shown* to be economically responsible. Value will receive greater attention.

The purpose of this paper is to evaluate a prospective supply enhancement for a representative Texas community. The employed procedure is broadly applicable because it is independent of the method of supply enhancement (reservoir construction, ground water development, water rights purchase, etc.). An important feature of the technique is the ability to analyze supply enhancements with differing temporal

---

[1] Paper No. 88151 of the *Water Resources Bulletin*. Discussions are open until December 1, 1990. (Technical Article 24281 of the Texas Agricultural Experiment Station.)

[2] Associate Professor, Department of Agricultural Economics, Texas A&M University, College Station, Texas 77843.

distributions during each year. Informational and computational burdens of the procedure are considerably less than that of related dynamic optimization models which select optimal capacity expansion and, possibly, prices (e.g., Dandy *et al.*, 1985). Emphasis is placed upon the investigation of the sensitivity of water value to potentially important parameters. That is, the analysis highlights illustration of the method and the qualitative nature of the results for a representative community.

## METHOD

The value of a supply increment can be assigned by computing consumer surplus measures (James and Lee, 1971; Young and Gray, 1972; Griffin and Stoll, 1983). Use of this technique has been graphically illustrated by Griffin and Stoll. Because of the dominance of average cost pricing, producer surplus is expected to be zero. The demand for residential water has been found to have low income elasticity (Chicoine *et al.*, 1986; Griffin and Chang, 1989). Therefore, as a technical matter only of interest to economists, Marshallian measures of consumer surplus well approximate exact Hicksian measures (Just *et al.*, 1982).

Knowledge of a point on a water demand function and slope or elasticity at the point permits local approximation of the function. A wide selection of functional forms is available. The Cobb-Douglas (or double logarithmic) form is chosen for the initial analysis because it is commonly employed in demand estimation and the approximated function lies in the same orthant as the initially known point (negative prices or quantities cannot be generated by a simulation program). A subsequent analysis employing a more "flexible" functional form is reported in a latter section. Fixing nonprice variables, the Cobb-Douglas demand function for a community is given by $Q = kP^{\varepsilon}$ where (Q,P) is the quantity and price of water, k is a constant, and $\varepsilon$ denotes price elasticity. Knowledge of an initial point ($Q_0$, $P_0$) and an estimated elasticity, $\varepsilon_0$, permits calculation of an initial constant, $k_0$, according to $k_0 = Q_0 P_0^{-\varepsilon_0}$. To protect future demand it is assumed that elasticity is fixed and the demand curve shifts rightward according to the population growth rate. Thus, demand is given by $Q_t = k_t P_t^{\varepsilon_0}$ where $k_t = (1 + g)^t k_0$ and g is the rate of population growth. Inverse demand is $P_t = (Q_t/k_t)^{1/\varepsilon_0}$.

If supply is initially constrained to $S_0$ and is subsequently increased to $S_1$, the value of this increment in period t is

$$V_t = \int_{S_0}^{S_t} [(Q_t / k_t)^{1/\varepsilon_0} - P_t] dQ_t \qquad (2)$$

where $S_t = \max[0, \min[S_1, k_t P_t^{\varepsilon_0}]]$ and $\min[S_1, k_t P_t^{\varepsilon_0}]$ denotes the amount of the new water supply that consumers wish to consume in period t. Price is assumed to increase over time at rate d (possibly zero) according to $P_t = (1 + d)^t P_0$. It can be shown that the utility's gross revenue at any point in time is given by $R_t = (1 + d(1 + \varepsilon))^t R_0$. The total value of the supply increment is computed as a net present value:

$$NPV = \sum_{t=1}^{T} V_t (1 + r)^{-t} \qquad (2)$$

with planning horizon T and discount rate r.

The advantages of this method are its computational ease, programmability, and flexibility. Various time increments can be chosen (years, days, etc.) and alternative population growth rates, discount rates, planning horizons, supply increments, etc., can be easily evaluated once programming is complete. By relying upon the community's recent experiences which are embedded in ($Q_0$,$P_0$), the method is customized to the local setting. By using price elasticities resulting from statistical analyses involving many communities, the method avoids the community's lack of experience with respect to alternative prices.

Disadvantages of this method pertain to potential sensitivities to the chosen functional form and the absence of stochastic considerations. Choice of the Cobb-Douglas form over a linear model is probably a large improvement, but important maintained results (i.e., results which are forced by the selected form) are still likely, especially if price changes take us far away from the point of local approximation. More complex forms may alleviate some of this criticism if they are carefully selected but the degree of this problem remains unknowable because the true form is unknown. Application of this general procedure using other functional expressions of demand is feasible only if the form is invertible and the inverted function is integrable. The invertibility requirement is very restrictive. Finally, the deterministic character of this procedure is a disadvantage if heightened consumer utility during droughty periods is not offset by lower assigned values during wet times.

Additional observations concerning this model are contributed by a reviewer. Letting $c = (1 + g)(1 + d)^{\varepsilon}$ and still defining $Q_0$ as current demand and $S_0$ as currently available supply, it can be easily shown that

$$t^* = \frac{\log(S_0 / Q_0)}{\log c} \quad (3)$$

denotes the time period in which supply becomes barely sufficient for future demand. Moreover, whether the quantity of water demanded rises, is constant, or falls depends only on whether c is greater than, equal to, or less than one.

## DATA

Most of the data for this analysis is derived from a recent study of monthly community water demand by 221 Texas communities during 1981-85 (Griffin and Chang, 1989). Table 1 contains average water consumption, average real prices, and elasticity estimates reported by Griffin and Chang. Prices incorporate both water and sewer rates because water demand has been determined to be influenced by both prices. The elasticity estimates are taken from a real price econometric model of monthly water demand employing the Generalized Cobb-Douglas functional form.

TABLE 1. Initial Conditions (Year 0).

| Month | Consumption (gal/cap/day) | Price ($/1000 gallons) | Elasticity |
|---|---|---|---|
| January | 134 | $1.64 | –0.31 |
| February | 135 | $1.67 | –0.30 |
| March | 137 | $1.63 | –0.35 |
| April | 158 | $1.59 | –0.37 |
| May | 169 | $1.54 | –0.38 |
| June | 189 | $1.51 | –0.39 |
| July | 223 | $1.46 | –0.41 |
| August | 230 | $1.45 | –0.41 |
| September | 197 | $1.50 | –0.39 |
| October | 150 | $1.62 | –0.36 |
| November | 135 | $1.70 | –0.33 |
| December | 135 | $1.70 | –0.31 |

A representative community of 10,000 people (population in year 0) is hypothesized to be enhancing its water supply by 48 acre-feet per year. This is roughly 2.5 percent of year 0's aggregate water consumption. The community possesses the characteristics identified in Table 1 for the average Texas city. A 50-year planning horizon is assumed, and a real monthly discount rate of 0.49 percent (6.0 percent annual) is assumed. [All prices, elasticities, and the discount factor are real, not nominal, and prices have been deflated by the monthly Consumer Price Index (U.S. Department of Commerce, 1987).]

The degree of extant excess supply capacity is important to value because it delays use of the supply increment. Application of the monthly model used here is potentially valuable in specifying capacity accurately and should yield better evaluations of certain types of increments, particularly peak-loading increments. Here is it presumed that the community's existing capacity ($S_0$) to deliver water in each month is given by peak (August) use plus 5 percent.

Separate scenarios are designed for the temporal distribution of the acquisition, population growth (g), and price growth (d). The purpose of these scenarios is to explore the sensitivity of water value to these potentially important parameters. Other factors may also warrant consideration, but the three selected for investigation here serve to focus the analysis. Factors such as per capita income, lot size, nonprice conservation effort, etc., are considered secondary because changes in these variables occur very slowly and are difficult to anticipate.

The scenarios of emphasis for this study concern alternate temporal distributions of the 48 acre-foot increment during each year. To illustrate the importance of temporal distributions, two scenarios are posited. In the first scenario the supply enhancement is equally allocated across all months (4 acre-feet per month). This scenario is most appropriate for supply enhancements due to ground water development and certain types of infrastructure improvements. In the second scenario the increment is equally distributed to the months of June, July, August, and September (12 acre-feet per month). This scenario best represents situations such as water right transfers in which the community can choose temporal distribution. The relative absence of legal impediments (such as minimum instream flows) and of binding capital constraints (such as reservoir storage capacity) is presumed for the second scenario.

Two population growth scenarios are used: 0.1 percent and 0.14 percent each month. These are equivalent to annual growth rates of 1.2 percent and 1.7 percent, respectively. The lower rate is approximately half of that experienced by Texas during the 1970's (Murdock *et al.*, 1981) and is slightly less than the low case employed in the 1984 statewide water plan which projects water requirements through 2030 (Texas Department of Water Resources, 1984). The high case used here approximates the high scenario of the state water plan.

Because this analysis uses real average prices, it might be reasonable to presume zero price growth. There is evidence, however, that the real cost of water to households is increasing. Deflating average prices by the Consumer Price Index, Griffin and Chang report that real water prices increased at an average rate of 8 percent annually from 1981 to 1985 while real sewer prices increased 12.4 percent annually. We presume that this price growth has been induced by the rising costs of water supply rather than by conservation policies. It therefore appears that continued rate growth is inevitable unless other revenue sources can be identified. In either case, costs (in terms of water/sewer bills or taxes) must be justified by the prospective benefits which are being calculated here. Three conservative price/cost growth scenarios are examined here: d = 0 percent, 2 percent, and 4 percent annually. Given the monthly elasticities and the previously noted formula for computing gross revenue change, revenue is growing at about two-thirds the rate of price growth.

## RESULTS

A computer program was developed to simulate these scenarios and calculate the value of the 48 acre-foot water increment in each month over the 50-year planning horizon (600 iterations). The program computes population; monitors demand, price, and available water; and calculates the previously given integral to compute value. Summary results for all 12 scenarios are reported in Table 2. The first three columns identify the scenario.

The fourth and fifth columns report the month/year during which some of the increment is first used and the first month/year of complete use. Years are enumerated as 01 to 50. Use of the increment typically increases over time but may rise and fall from month to month depending on the scenario. The first month of complete use identifies the first month of full use succeeded by full use of the increment in all months. By definition, this month is preceded by the last month of partial use of the increment. For certain scenarios, full use of the increment is never achieved during the 50-year period. In extreme cases involving high price growth (d = 0.04), no part of the increment is ever used because growing demand is more than offset by the price sensitivity of consumers. In these cases the water supply enhancement has no value to the community.

The next three columns identify aggregated monthly net present value in each of the final two years as well as NPV over all 600 months. The purpose of including NPV's accruing during individual years is to show that, in some cases, NPV is still increasing at an increasing rate at the conclusion of the planning horizon. Further analysis demonstrates that annual NPV begins to decline if the planning horizon is extended. NPV ranges widely across the evaluated scenarios. The value of community water increments is clearly sensitive to temporal distribution, population growth, price increases, and planning horizon. It is noteworthy that the reported values have netted out normal production costs captured by future water prices ($P_t$) but exclude any fixed costs which might be associated with developing, purchasing, and connecting the

TABLE 2. Water Value for Individual Scenarios – Cobb-Douglas Model.

| **Scenario*** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Temporal Distribution** | **g** | **d** | **First Use (month/year)** | **Complete Use (month/year)** | **$NPV_{49}$** | **$NPV_{50}$** | **NPV** | **NPV/AF** |
| All Months | 0.001 | 0.00 | 8/05 | – – | $1,098 | $1,101 | $34,653 | $ 722 |
| | | 0.02 | 8/14 | – – | 200 | 200 | 4,633 | 97 |
| | | 0.04 | – – | – – | 0 | 0 | 0 | 0 |
| | 0.0014 | 0.00 | 8/04 | 3/42 | 3,320 | 3,347 | 86,780 | 1,808 |
| | | 0.02 | 8/07 | – – | 1,286 | 1,302 | 31,464 | 656 |
| | | 0.04 | – – | – – | 0 | 0 | 0 | 0 |
| Summer Months | 0.001 | 0.00 | 8/05 | 7/27 | 2,554 | 2,524 | 87,432 | 1,821 |
| | | 0.02 | 8/14 | – – | 503 | 505 | 9,934 | 207 |
| | | 0.04 | – – | – – | 0 | 0 | 0 | 0 |
| | 0.0014 | 0.00 | 8/04 | 7/20 | 5,714 | 5,680 | 192,498 | 4,000 |
| | | 0.02 | 8/07 | 7/37 | 3,317 | 3,346 | 80,366 | 1,674 |
| | | 0.04 | – – | – – | 0 | 0 | 0 | 0 |

*g is the monthly rate of population growth, and d is the annual rate of real price growth.

supply increment. Therefore, the assessments given in Table 2 are not net benefits of the supply increment until the fixed costs are subtracted.

The final column of Table 2 contains net present value per acre-foot, which is the average value of the supply increment. Values range from \$0 to \$4,000 per acre-foot. The lowest values emerge for the equal distribution of the increment across all months because nonsummer supply increments are less valuable and are not needed until later years. Summer water increments have at least twice the value of an equally apportioned increment according to these results. Changes in population growth also influence value substantially. Water rate increases are found to have crucial impacts upon value because price-induced conservation postpones use of the increment, perhaps indefinitely. Clearly, these findings indicate that if water rates continue to grow in Texas at even half the rate they did from 1981 to 1985, then supply enhancements will not be beneficial.

## TRANSLOG RESULTS

A natural question arising from this procedure concerns the sensitivity of results to the selected functional form. Few alternatives to the Cobb-Douglas model are available because of the invertibility and integrability requirements cited previously. Further consideration suggests three options satisfying these requirements: linear ($Q = a + bP$), shifted Cobb-Douglas ($Q = kP^{\varepsilon} + M$), and Translog ($\log Q = \log K + \alpha \log P + \beta (\log P)^2$).

To investigate use of the Translog form for evaluating the same scenarios previously considered, note that (1) this form can be rewritten as $Q = kP^{\alpha+\beta \log P}$ and (2) the original Translog expression is quadratic in log P whenever Q is known. Observation (1) clearly shows the Translog form to be a generalization of the Cobb-Douglas form. Proceeding in a similar fashion to the Cobb-Douglas case, $Q_0$, $P_0$, and $\varepsilon$ data from Table 1 are used to determine a $k_0$ for each month. To also obtain $\alpha_0$ and $\beta_0$ I select $\beta_0$ from econometric results using the Translog form and the cited 221-community, five-year data set: $\beta_0 = 0.0217$ (*t*-statistic = 2.02). Applying $\varepsilon = \alpha + \beta \log P$ with this selection permits $\alpha_0$ to be calculated for each month. Monthly demand can now be projected according to

$$Q_t = k_t P_t^{\alpha_0 + \beta_0 \log P_t} \tag{4}$$

$$k_t = (1+g)^t k_0 \text{ and}$$
$$P_t = (1+d)^t P_0$$

It can now be seen that the Translog form is arguably better than the Cobb-Douglas form, because the Translog form is congruent with the following expectation (since $\beta_0 > 0$). It is to be expected that price increases induce conservation effort by consumers, but, as conservation opportunities are progressively exhausted, the price sensitivity of consumers wanes. The Cobb-Douglas form maintains constant price sensitivity along the demand curve and is therefore in conflict with this expectation.

To obtain inverse demand and thereby construct an integrable expression for consumer surplus, I employ observation (2) to obtain

Therefore,

$$\log P_t = \frac{-\alpha_0 \pm \sqrt{\alpha_0^2 - 4\beta_0 \log(k_t / Q_t)}}{2\beta_0} \tag{5}$$

where

$$V_t =$$

$$\int_{S_0}^{S_t} \left[ \exp\left( \frac{-\alpha_0 \pm \sqrt{\alpha_0^2 - 4\beta_0 \log(k_t / Q_t)}}{2\beta_0} \right) - P_t \right] dQ_t \tag{6}$$

Unlike the Cobb-Douglas case, numerical techniques are now needed to evaluate the integral and obtain

$$S_t = \max\left[0, \min\left[S_1, k_t P_t^{\alpha_0 + \beta_0 \log P_t}\right]\right].$$

Use of the – portion of the ± sign is necessary to obtain sensible values for the preceding integral. Results are reported in Table 3 for the 12 postulated scenarios. Findings are qualitatively similar to the Cobb-Douglas results of Table 2. Summer supply augmentations still offer twice the value of equally apportioned enhancements. The effects of variable population and price growth rates are again dramatic. Two additional observations are noteworthy, and both stem from the Translog model's declining price sensi-

TABLE 3. Water Value for Individual Scenarios – Translogly Model.

| Scenario* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Temporal Distribution** | **g** | **d** | **First Use (month/year)** | **Complete Use (month/year)** | **$NPV_{49}$** | **$NPV_{50}$** | **NPV** | **NPV/AF** |
| All Months | 0.001 | 0.00 | 8/05 | – – | $1,211 | $1,219 | $36,674 | $ 764 |
| | | 0.02 | 8/14 | – – | 283 | 285 | 6,236 | 130 |
| | | 0.04 | – – | – – | 0 | 0 | 0 | 0 |
| | 0.0014 | 0.00 | 8/04 | 3/42 | 3,951 | 4,015 | 96,100 | 2,002 |
| | | 0.02 | 8/07 | – – | 1,846 | 1,909 | 40,001 | 833 |
| | | 0.04 | 8/32 | – – | 194 | 214 | 1,518 | 32 |
| Summer Months | 0.001 | 0.00 | 8/05 | 7/27 | 2,839 | 2,818 | 92,508 | 1,927 |
| | | 0.02 | 8/14 | – – | 726 | 734 | 13,929 | 290 |
| | | 0.04 | – – | – – | 0 | 0 | 0 | 0 |
| | 0.0014 | 0.00 | 8/04 | 7/20 | 7,093 | 7,123 | 214,577 | 4,470 |
| | | 0.02 | 8/07 | 7/35 | 4,696 | 4,788 | 101,986 | 2,125 |
| | | 0.04 | 8/32 | – – | 346 | 394 | 2,368 | 49 |

*g is the monthly rate of population growth, and d is the annual rate of real price growth.

apportioned enhancements. The effects of variable population and price growth rates are again dramatic. Two additional observations are noteworthy, and both stem from the Translog model's declining price sensitivity at higher prices. First, water values are higher when the Translog model is employed. Second, the water acquisition may have value even when average water costs are increasing at the 4 percent annual rate.

## CONCLUSIONS

Both Cobb-Douglas and Translog findings demonstrate that there is no single value of urban water. Water value is strongly dependent upon economic and physical conditions faced by the individual city. In many such instances the examination of value using annual data and an annual expression of demand can easily misstate value. Assessments employing monthly constructs are desirable and feasible. Simply stated, summer water is more valuable than nonsummer water. Finer time increments are needed to adequately assess the value of supply improvements with greater temporal definition than that considered here. Water value is also strongly sensitive to population growth and growth in average costs. Potential growth in average costs is particularly problematic in that it is an excluded factor in typical deliberations involving prospective supply acquisitions. Based on the quantitative findings of this study, additional attention to this point is needed lest consumers or taxpayers become obligated for unnecessary water development debts.

The value of urban water acquisitions can be large in particular cases but so can the costs (including transaction and planning costs). Adding the costs of transacting and the fixed costs of linking and delivering the supply increment can increase the true costs of water right purchases substantially. Based on cost considerations and the results obtained here, many potential acquisitions may not be beneficial in net, and careful analyses of value are needed to accurately assess benefits. Other costs and benefits may need to be incorporated. The valuation procedure developed here is, however, easily programmed and can be customized in several ways. Community planners and decision makers should welcome informational input of this type.

## LITERATURE CITED

Chicoine, David L., Steven C. Deller, and Ganapathi Ramamurthy, 1986. Water Demand Estimation Under Block Rate Pricing: A Simultaneous Equation Approach. Water Resources Research 22:859-863.

Dandy, Graeme C., Edward A. McBean, and Bruce G. Hutchinson, 1985. Pricing and Expansion of a Water Supply System. Journal of Water Resources Planning and Management 111:24-42.

Gibbons, Diana C., 1986. The Economic Value of Water. Resources for the Future, Washington, D.C.

Griffin, Ronald C. and Chan Chang, 1989. Community Water Demand in Texas. Texas Agricultural Experiment Station, Texas A&M University, College Station, Texas, B-1625.

Griffin, Ronald C. and John R. Stoll, 1983. The Enhanced Role of Water Conservation in the Cost-Benefit Analysis of Water Projects. Water Resources Bulletin 19:447-457.

James, L. Douglas and Robert R. Lee, 1981. Economics of Water Resources Planning. McGraw-Hill Book Co., New York, New York.

Just, Richard E., Darrell L. Hueth, and Andrew Schmitz, 1982. Applied Welfare Economics and Public Policy. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Murdock, Steve H., R. L. Skrabanek, S. Hwang, and R. R. Hamm, 1981. City and Small Town Population Growth in Texas in the 1970's. Department of Rural Sociology, Texas A&M University, College Station, Texas, DTR 81-4.

Texas Department of Water Resources, 1984. Water for Texas. Austin, Texas, Vols. 1 and 2.

U.S. Department of Commerce, Bureau of Economic Analysis, 1987. Business Statistics, 1986. U.S. Government Printing Office, Washington, D.C.

Water Market Update (various issues and years). Shupe and Associates, Inc., Santa Fe, New Mexico.

Young, Robert A. and S. Lee Gray, 1972. Economic Value of Water: Concepts and Empirical Estimates. NTIS Report, PB-210-356, National Technical Information Service, Springfield, Virginia.

Young, Robert A., Joel R. Hamilton, Norman K. Whittlesey, Richard L. Gardner, and William E. Martin, 1988. Discussion: Aggregate Marginal Returns From Western Irrigated Agriculture. Water Resources Bulletin 24(6):1337-1339.