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David S. Brookshire

H. Stuart Burness

Janie M. Chermak

Kate Krause

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DAVID S. BROOKSHIRE, H. STUART BURNES, JANIE
M. CHERMAK, & KATE KRAUSE*

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ABSTRACT

Increasing concern with sustainability issues has raised questions regarding western water use. Efficient water allocation requires policy tools based on the value of water in alternative uses: agricultural, environmental, residential, and others. Agricultural values are fairly well established. Environmental values are recognized as "non-market" and estimated with various alternative techniques. Residential uses are normally thought to be market determined, but these markets are often restricted, allowing the possibility that water charges may not accurately reflect the value of water. This article reviews the history of urban residential water data analyses in order to address this and related issues and to ascertain the efficacy of extant databases. We then investigate the viability of estimated demand relationships and the robustness of these estimates to potential policy needs. We also discuss relevant conceptual issues for effective water policy formulation and their role in remedying data inadequacies and provide some gross estimates for water prices that include all relevant costs. Finally, we synthesize the data review and conceptual issues to identify the requirements for broadening the urban-residential water database. Efficient water pricing in environments where water is "scarce" relies on rules that modify extant pricing practices to include a scarcity value. The process has implications for empirical analyses; therefore, we sketch some alternatives for conducting these analyses that could assist policy makers in making difficult water pricing decisions.

1.0 INTRODUCTION

The future viability of the arid Southwest will depend in large part on efficient use of increasingly scarce water resources. Exogenous factors, such as climate change and population growth, may exacerbate problems currently not considered threatening. Policymakers may have to consider

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demand side management as a future policy tool. Concomitant policy formulation requires an appropriate model of water use and a database adequate to support the policy analysis. While extensive effort has been directed to various modeling issues, questions concerning the suitability of the available data for policy analysis have received less attention. An analysis of extant urban-residential water data reveals anomalies that raise questions as to the applicability of current empirical demand estimates for deriving conservation oriented policy plans.

Water resources, long recognized as critical in the arid Southwest, as well as in much of the rest of the western United States, will face increased demands. Current U.S. migration trends and the recognized potential for climatic change promise increased municipal and agricultural water demands. In addition, changing preferences have increased water demand for, among other things, the support of wildlife and the maintenance of instream and riparian habitat and increased power generation.

Responses to these allocational issues impose additional demands on already limited water supplies and have unavoidable and obvious distributional consequences.¹ Additionally, many communities allude to often broadly and sometimes vaguely-stated "sustainable use" objectives.

Addressing these issues involves policy tools commonly falling under the rubric of "demand side management." These policy tools require that decision makers evaluate the tradeoffs between alternative current and future uses of water. While some water uses have well-defined market-determined values (*e.g.*, agricultural uses), other values are less well prescribed (*e.g.*, environmental and recreational values, etc.). Urban use values might seem to be well defined, but many of these water markets are restricted. Consequently, water charges and the "shadow value" of water (the value foregone of holding the water for future use) may diverge, frustrating attempts to specify the relevant tradeoffs between alternative current and future uses of water.

Consensus has it that in the arid and semi-arid areas of the western United States water is a "scarce" commodity; however, scarcity is not a stand-alone concept. In fact, it is a meaningless concept unless qualified and accompanied by a price. For example, given current market conditions, gold, at \$2000/ounce, is not scarce; any broker would be willing to sell as much as one will buy at that price; supply will outpace demand. However, in these same market conditions, at \$100/ounce, gold is scarce, with demand outweighing supply. Nonetheless, allusions to the scarcity of water

1. In the end, water supply is fixed; there is a set quantity of water available on the earth. While water can be moved from place to place by institutional and/or technological changes, the cost of such changes may be prohibitive.

in the west are not misguided. Most western water is at least moderately "under priced" for a variety of reasons including the following:

- i) Many users of water from the U.S. Bureau of Reclamation storage projects continue to receive significant implicit subsidies resulting from repayment schemes originally intended to spur western development.²
- ii) It is estimated that while current water charges, on average, cover 90 percent of the immediate costs to build, operate, and maintain water and wastewater systems,³ the future shortfalls may be as much as 50 percent under current pricing structures.⁴
- iii) Groundwater users face common pool problems. Increased pumping costs and other externalities result in current water costs that are significantly less than the scarcity value of water.⁵
- iv) Municipal water suppliers usually base water charges on cost recovery so that water charges are typically significantly less than the scarcity value of water.

2. See, e.g., H.S. Burness et al., *United States Reclamation Policy and Indian Water Rights*, 20 NAT. RESOURCES J. 807 (1980); MARC REISNER, *CADILLAC DESERT: THE AMERICAN WEST AND ITS DISAPPEARING WATER* 114 (1986).

3. Water Infrastructure Network, *Clean and Safe Water for the 21st Century* (Apr. 2000), at http://www.win-water.org/win_reports/pub2/pub_2_html/safe_clean_water.html (last visited Aug. 25, 2002).

4. While there is considerable variation in the estimated costs of maintaining or upgrading infrastructure, there is general consensus in the research that additional money is necessary. Compare *id.*; Ronnie B. Levin et al., *U.S. Drinking Water Challenges in the Twenty-first Century*, 110 ENVTL. HEALTH PERSP. 43 (2002) (Supplement 1); U.S. ENVIRONMENTAL PROTECTION AGENCY, *DRINKING WATER INFRASTRUCTURE NEEDS SURVEY* (2001). The U.S. Environmental Protection Agency (EPA) estimates an additional \$48 billion is necessary over the next 20 years, while the Water Infrastructure Network (WIN) estimate is \$11 billion per year. The EPA acknowledges, however, that their estimate is based only on surveyed needs for the next five to ten years, which results in a low estimate; they also acknowledge that many utilities surveyed do not have infrastructure plans even though they are needed. This also may bias the forecast estimate downward.

5. Scarcity value, or user cost, is the discounted future value foregone by consuming a unit of a resource in the present, rather than holding for the future. For more on the impact of pumping costs or externalities, see Bill Provencher & Oscar Burt, *The Externalities Associated with the Common Property Exploitation of Groundwater*, 24 J. ENVTL. ECON. & MGMT. 139, 156 (1993); David S. Brookshire, Janie M. Chermak & Mary Ewers, *Borders Crossing Borders: Efficiency and Equity Considerations of Groundwater Markets in the Ciudad Juárez/El Paso Region Along the Mexico/United States Border*, in 26 INT'L SEMINAR ON NUCLEAR WAR AND PLANETARY EMERGENCIES 264 (2002).

Given these observations, the basis for statements concerning the scarcity of western water becomes self-evident. The problems in (i) and (iii) have generated considerable dialogue in the literature and (ii) has received most attention from industry and government groups; however, (iv) has received relatively little attention.

In this article, we focus mainly on (iv). To the extent that policy concerns embrace notions of intertemporally sustainable use of water resources, accurate valuations of water in *all* uses are requisite to stipulating the relevant trade-offs among alternative uses. If policy makers wish to rely on markets to ration water supplies, prices must be allowed to attain their unrestricted equilibrium levels. Otherwise, one must face the specter of either mandatory rationing or premature depletion of water supplies. Given that almost 80 percent of water provided by community water systems is from groundwater,⁶ the threat of depleting water supplies prematurely is a major concern.

We develop the basis for establishing the shadow value or scarcity value pricing for urban residential water use and identify some of the analytical and empirical problems encountered in this endeavor. We begin by presenting a review of the extant literature concerning urban residential water demand and analyze its suitability for developing policy prescriptions towards the end of efficient water use. While the techniques are for the most part sound, the range of empirical data is limited; *i.e.*, estimated models may only be applicable over a very narrow range of prices. While concerns involving current or expected water shortages are frequently expressed, we find that urban-residential water prices have not increased significantly over the past 40 years. The empirical analysis suggests several conceptual issues relevant to the quest for an improved database, which in turn form the basis for policy recommendations.

2.0 BACKGROUND

Numerous studies of urban-residential water demand and elasticities have appeared since the 1960s. These studies have considered the role of time-periods (*e.g.*, summer versus winter), location, the level of aggregation, pricing structures (*e.g.*, various block rates), both average and marginal pricing rules, climatic variables, and in some cases economic or household characteristics. The studies have included (i) cross-sectional analyses, considering the behavior of a cross-section of consumers at a single point in time; (ii) time series analyses, considering the behavior of either a single or "representative" consumer over time; as well as (iii) panel

6. U.S. ENVIRONMENTAL PROTECTION AGENCY, COMMUNITY WATER SYSTEM SURVEY: 1995 6 (1997), available at <http://www.epa.gov/safewater/cwsreprt.pdf>.

analyses, considering the behavior of the cross-section over time. While many of the studies focus solely on price, some of the studies incorporate household or economic characteristics into the analysis. Due to the wide range of studies, we review the works chronologically.

In 1967, Howe and Linaweaver published a seminal paper estimating own price residential water elasticities for various geographic regions across the United States.⁷ They utilized a cross-sectional data set of average consumer values for 39 geographic areas, sorted into five distinct categories with demand dichotomized as to "in-house" or "sprinkling" uses. Econometrically tested factors included marginal price,⁸ market value of property, size of household, irrigable areas, total water and sewage charges, and average income level. Howe and Linaweaver found marginal price to be significant in two of the five categories. Price elasticity for in-house demand was calculated as -0.23 , while sprinkling demand price elasticity was estimated as -1.57 . Property value, household size, climate factors, and income were determined to be statistically significant.⁹ The results of this research were influential in the formulation of subsequent policy.

The Howe and Linaweaver analysis prompted significant professional discussion from which at least two major conclusions emerged. First, the fact that many water utilities use some form of block rate¹⁰ structure for water charges raised concerns as to whether the Howe and Linaweaver econometric analysis accurately reflected the role of prices. Their econometric formulation did not adequately allow for block rate structures. Second, it was suggested that the analysis should be conducted at the level of a single household, rather than at the level of a water utility.

7. Charles W. Howe & F.P. Linaweaver, *The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure*, 3 WATER RESOURCES RES. 13 (1967).

8. Marginal price is the price for the last unit of water purchased as opposed to average price, which is the average water charge per unit over a billing period. It has been suggested that water use is insensitive to marginal price, as these price changes are only perceived at the end of the billing period. However, this is not universally accepted.

9. Own-price elasticity is the responsiveness of the quantity demanded to a change in price. The measure can be interpreted as the percentage change in the quantity demanded, given a one percent change in price. Thus, the -0.23 measure signifies a 0.23 percent change in quantity demanded, given a one percent change in price, while the 1.57 measure signifies a 1.57 percent change in the quantity demanded, given a one percent change in price. In absolute terms, if the measure is greater than one, the good is considered elastic (responsive to price), while an absolute value of less than one is considered inelastic or unresponsive.

10. Block rate pricing is a pricing schedule in which prices vary with blocks of units. The units in the first block will have a unit price, x , charged for each unit. The second block will have some unit price, y , charged for each unit. If $x < y$, it is an increasing block rate structure, while if $x > y$ it is a declining block rate structure.

The first conclusion spawned voluminous literature that focused on the role of alternative block rate price structures in the analysis, including articles by Gibbs,¹¹ Foster and Beattie,¹² Howe,¹³ Nieswiadomy,¹⁴ and Renwick and Green.¹⁵ These studies were all conducted at either a regional or an agency level and focused on average consumer use. Consumer identifying data, if used, was generally obtained from the respective agencies or from census data and limited to average characteristics. The second conclusion, concerning the appropriate level of analysis, resulted in additional research at the level of a single household. Some studies used only actual use data, while others included survey data from the household. Included in this research are articles by Danielson,¹⁶ Jones and Morris,¹⁷ Nieswiadomy and Molina,¹⁸ Rizaiza,¹⁹ Lyman,²⁰ Martin and Wilder,²¹ Hewitt and Hanemann,²² and Renwick and Archibald.²³

Table 1 summarizes regional and agency studies and Table 2 summarizes household level studies. Both report only post Howe and Linaweaver studies. These studies report a range of own price elasticities that, with the exception of the Howe and Linaweaver, Lyman, and Hewitt and Hanemann studies, are less than one (in absolute value), indicating the

11. K.C. Gibbs, *Price Variable in Residential Water Demand Models*, 14 WATER RESOURCES RES. 15 (1978).

12. H.S. Foster, Jr. & B.R. Beattie, *On the Specification of Price in the Study of Domestic Water Demand*, 57 LAND ECON. 624 (1981).

13. C.W. Howe, *The Impact of Price on Residential Water Demand: Some New Insights*, 18 WATER RESOURCES RES. 713 (1982).

14. M.L. Nieswiadomy, *Estimating Urban Residential Water Demand: Effects of Price Structure, Conservation, and Education*, 28 WATER RESOURCES RES. 609 (1992).

15. M. Renwick & R. Green, *Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies*, 40 J. ENVTL. ECON. & MGMT. 37 (2000).

16. L.E. Danielson, *An Analysis of Residential Demand for Water Using Micro Time-Series Data*, 15 WATER RESOURCES RES. 763 (1979).

17. C.V. Jones & J.R. Morris, *Instrumental Price Estimates and Residential Water Demand*, 20 WATER RESOURCES RES. 197 (1984).

18. M.L. Nieswiadomy & D.J. Molina, *Comparing Residential Water Demand Estimates under Decreasing and Increasing Block Rates Using Household Data*, 65 LAND ECON. 280 (1989).

19. O. Rizaiza, *Residential Water Usage: A Case Study of the Major Cities of the Western Region of Saudi Arabia*, 27 WATER RESOURCES RES. 667 (1991).

20. R.A. Lyman, *Peak and Off-Peak Residential Water Demand*, 28 WATER RESOURCES RES. 2159-67 (1992).

21. R. Martin & R. Wilder, *Residential Demand for Water and the Pricing of Municipal Water Services*, 20 PUB. FIN. Q. 93 (1992).

22. Julie A. Hewitt & W. Michael Hanemann, *A Discrete/Continuous Choice Approach to Residential Water Demand Under Block Rate Pricing*, 71 LAND ECON. 173 (1995).

23. Mary E. Renwick & Sandra O. Archibald, *Demand Side Management Policies for Residential Water Use: Who Bears the Conservation Burden?*, 74 LAND ECON. 343 (1998).

demand for water is inelastic for the relevant price ranges.²⁴ Many of the results indicate that factors other than price influence water demand. Variables that may be correlated with income (such as property value and lot size) are also significant in some studies. Other significant variables are location specific, such as climate. This suggests residential water consumers are heterogeneous and that individual differences count. Income and household size are significant in many of the studies.

3.0 APPLICABILITY OF RESULTS

The range of reported elasticities suggests that water demand is generally inelastic, indicating, in turn, that price may not be a particularly effective policy tool for curtailing water consumption. However, one must consider the range of prices under which these studies were conducted. This allows a consideration of the applicability of future policy prescriptions within the price range studied. If the price range is not applicable, it allows speculation as to whether the study results might be robust as to prices outside the studied range. While not all of the studies reported prices, some of them did. Figure 1 presents reported prices from the relevant U.S. studies. To facilitate comparisons, all prices have been converted to 2000 dollars and are reported in dollars per gallon of water.

As the graph shows, historical prices are very low. They range from \$0.0001 per gallon in Wisconsin in 1979 to a high of \$0.0035 per gallon in Raleigh, North Carolina in 1973. The average per gallon price from these studies is \$0.0022.²⁵

There do not appear to be significant systematic differences in water charges either temporally or spatially. These observations raise several issues. It may be that there were no significant market changes since the 1960s. Alternatively, there may have been offsetting supply and demand movements. Finally, water charges may not reflect actual scarcity values.

While there have been changes in the U.S. urban-residential water markets, there is little to indicate that the combination of observed changes in supply and demand would lead to stable water prices over long time periods. In fact, while the daily per capita withdrawals from public sources declined from 184 gallons per day (gpd) in 1990 to 179 gpd in 1995, a decline of roughly three percent, total water withdrawals increased approximately four percent, due to a seven percent increase in population

24. In all cases, the exceptions to the absolute value greater than one occurred in what could be considered peak periods.

25. To put this in perspective, the commodity charge for one ten-minute shower each day for a month, using a 7.5-gallon per minute showerhead, would be \$5.00.

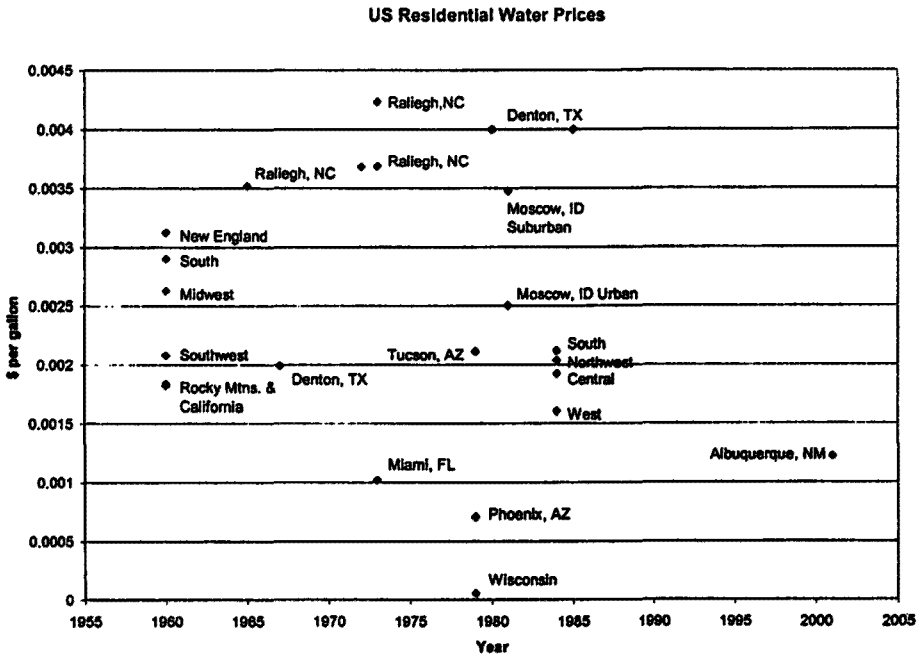
TABLE 1: SUMMARY OF REGIONAL OR AGENCY STUDIES

Study	Year	Data Level	Observation Period	Time Horizon	Location	Elasticity	Other Significant Variables
Howe and Lineaweaver	1967	x-section	Annual	1963-1967	Eastern U.S.	-0.86	
Gibbs	1978	x-section	Quarterly	1973	Western U.S. Miami	-0.52 -0.51 (marginal price) -0.62 (average price)	Household Size, Seasonal, Income
Foster and Beattie	1979	x-section	Annual	1960	Midwest South Rocky Mountains	-0.67 (Great Bend, IN) -0.44 (Huntsville, AL)	Household Size, Income
Howe	1982	x-section	Annual	1963-1967	Winter Eastern Summer	-0.76 (Colorado Springs, CO) -0.06 -0.57	Climatic Variables
Nieswiadomy	1992	x-section	Monthly	1984	North Central U.S. Northeast South West	-0.11/-0.28 (marginal price/average price) NS/-0.22 (marginal price/average price) -0.17/-0.60 (marginal price/average price) -0.17/-0.45 (marginal price/average price)	Climatic Variables, Household Size, Public Education
Renwick and Green	2000	panel	Monthly	1989-1996	San Francisco, Contra Costa, San Bernadino, Santa Barbara, San Diego, Marin, Los Angeles, and East Bay	-0.16/-0.20 (winter/summer)	Information, Subsidies, Rationing, Income, Lot Size, Climatic Variables

TABLE 2: SUMMARY OF HOUSEHOLD STUDIES

Study	Year		Data Level	Observation Period	Time Horizon	Location	Elasticity	Other Significant Variables
Danielson	1979		panel	Monthly	1969-1974	Raleigh, NC	-0.27 (combined) -0.31 (winter) -0.36 (summer)	Property Value, Household Size, Climatic Variables
Jones and Morris	1984		x-section	Monthly	1976	Denver, CO	-0.18 to -0.34 (average price) -0.7 to -0.21 (marginal price)	Income, Household Size
Nieswiadomy and Molina	1989		panel	Monthly	1976-1985	Denton, TX	-0.26 to -0.86	Income, Lawn Size, Climatic Variables,
Rizaiza	1991		x-section	Annual	1986	Jeddah, Makkah, Medina, and Taif Saudi Arabia	-0.40 (supplied by tanker) -0.78 (public system)	Household Size, Income, Climatic Variables,
Lyman	1992		panel	Monthly	1983-1987	Moscow, ID	-1.35/-0.43 (peak/off-peak)	Income, Property Value Age Distribution,
Martin and Wilder	1992		panel	Monthly	1980-1981	Columbia, SC	-0.60/-0.70 (marginal price/average price: urban) -0.32/-0.49 (marginal price/average price: suburban)	Martin and Wilder
Hewitt and Hanemann	1995		panel	Monthly	1976-1985	Denton, TX	-1.59 (summer)	Climatic Variables, Lawn Size
Dandy and Nguyen	1997		panel	Monthly	1987	Adelaide, Australia	-0.29/-0.86 (winter/summer)	Property Value, Pool,
Renwick and Archibald	1998		panel	Monthly	1985-1990	Santa Barbara and Goleta, CA	-0.33	Household Size, Income

FIGURE 1: HISTORICAL RESIDENTIAL U.S. WATER PRICES



over the same time period.²⁶ With no apparent change in water charges, the decline in per capita withdrawals is consistent with a shift in demand, due perhaps to changes in tastes and preferences. One would expect that the overall increase in withdrawals would be accompanied by an increase in price, all else equal. An increase in withdrawals, accompanied by either a decline or no change in price, could occur if a change in technology leads to at least a proportional increase in water supplies (this does not seem to be indicated). Alternatively, as municipal water supplies are generally characterized by declining marginal costs, water pricing is often based on cost recovery (average cost pricing). Consequently, scarcity values are not reflected in water charges, and the lack of observed price trends are not surprising.

Furthermore, the value of water is determined by both demand and supply considerations in concert. Important factors that impact water

26. U.S. GEOLOGICAL SURVEY, CIRCULAR NO. 1200, ESTIMATED USE OF WATER IN THE UNITED STATES IN 1995 20 (1998).

supply in semi-arid regions include the timing, location, and reliability of precipitation, as well as institutional factors. In the United States, annual precipitation generally declines in an east to west direction. Some areas in the southeast receive in excess of 60 inches of rain per year, while some areas in the desert southwest receive less than five inches.²⁷ Large variations in supply exist. Accordingly, based on scarcity values, one would not expect water charges to be so uniform. In fact, if water prices were market determined, one would expect the price of water to vary inversely with overall water availability. The observed pattern of water charges is consistent with the fact that the charges are usually based on cost recovery as opposed to scarcity value.²⁸ Thus, empirical studies of urban-residential water demand do not present a complete picture of water demand-price relationships.

Has the growing concern in the United States over the availability of water resulted in pricing changes? That is, is there a discernable difference between the historic prices found in Figure 1 and in 2001 commodity charges for water? Table 3 presents 2001 commodity charges for a sample of water utilities across the United States.²⁹ As can be seen, prices vary from \$0.0006 to \$0.0068 per gallon, a range of roughly one order of magnitude. Comparing these prices with the historical prices presented in Figure 1, the mean for the historical prices is \$0.0022 per gallon, with a standard deviation of .00000094, while the mean of the current prices is \$0.0023 with a standard deviation of 0.0000068.³⁰ A calculated t-statistic of -0.125 indicates that there is no statistically significant difference between the current and historical commodity prices for these two data sets. Apparently, even with increased awareness of water scarcity, water prices have not increased significantly.

This lack of significant variability in water prices over the last 40 years makes it difficult to empirically estimate demand functions. The results can only be as good as the data. Forecasting consumer response outside the range of data from which the function was estimated introduces a tremendous amount of uncertainty. Thus, such estimates generally are

27. Kenneth D. Frederick, *America's Water Supply: Status and Prospects for the Future*, 1 CONSEQUENCES, Spring 1995, at <http://www.gcrio.org/CONSEQUENCES/spring95/toc.html>.

28. Evidence of this is suggested by an EPA survey of rate structures. They report that 49 percent of community water systems surveyed rely on a uniform rate system, 25 percent on some type of flat fee, 16 percent on a decreasing block rate structure, only 11 percent on an increasing block rate structure, and less than one percent on a peak rate structure. U.S. ENVIRONMENTAL PROTECTION AGENCY, *supra* note 6, at 15.

29. Prices were gathered from various links at <http://www.utilityconnection.com> between June 15 and July 5, 2001.

30. This average price is similar to that of \$0.00294 reported by the EPA. U.S. ENVIRONMENTAL PROTECTION AGENCY, *supra* note 6, at 14.

TABLE 3: CURRENT WATER COMMODITY CHARGES

Location	\$/gallon	Comments	Rate Structure
Sierra Vista, AZ	0.0015	First 1000 gallons included in base-charge	Flat
Minnesota	0.0016 0.0010 0.0006	First 30,000 after minimum included in base-charge Next 470,000 gallons All additional gallons	Decreasing Block
Falls Water, ID	0.0003	First 20,000 included in base-charge	Flat
Henrico, VA	0.0015 0.0023	If use less than 4488 gallons bi-monthly If use more than 4488 gallons bi-monthly	Two-Tier
Lubbock, TX	0.0015	Single-family residence.	Flat
Mammoth, CA	0.0010 0.0012 0.0015 0.0021 0.0029 0.0041 0.0056 0.0060 0.0063 0.0068	First 4000 gallons Next 4000 gallons Next 4000 gallons Next 4000 gallons Next 4000 gallons Next 4000 gallons Next 4000 gallons Next 1000 gallons Next 1000 gallons All additional gallons	Increasing Block
Melbourne, FL	0.0021 0.0024	Inside City Limits Outside City Limits	Two-Tier
Tucson, AZ	0.0020 0.0027	First 23,000 gallons after minimum included in base-charge Summer conservation charge for any amount over 15,000 gallons per month	Tiered
	0.0034	For any amount in excess of 25,000 gallons per month	
Providence, RI	0.0011 0.0013	Field's Point Bucklin Point	Location Specific
Nashville, TN	0.0026	First 1496 gallons included in base charge	Flat
Portland, OR	0.0013 0.0015 0.0019	First 26,928 gallons Next 17,952 gallons All additional gallons	Increasing Block
Springfield, MO	0.0010 0.0022 0.0008	First 3740 gallons Next 216,920 gallons All additional gallons	Block*
Albuquerque, NM	0.0014	All gallons	Flat

* An increasing and then decreasing block rate.

unreliable. Given this, we surmise that the available studies are inadequate for forecasting consumer responses over the price ranges likely to reflect water's true scarcity value. Furthermore, while the studies indicate heterogeneity across consumer groups, there is little available information concerning pricing response differences across these groups. Lastly, the differences in response between summer and winter (or indoor and outdoor) usage in some of the studies suggest that, indeed, there may be several different uses that make up the demand for water.

These uses may be primary and direct or they may be indirect and related to the production of a final good consumed by the individual such as a green lawn or a clean car. In these cases, the production of a non-market good or service creates a derived demand for water. With water charges artificially low, the production of these goods may be dominated more by considerations pertaining to the cost of other inputs in the production process. Consequently, decisions concerning water use may be subjugated to other concerns, and the relatively cheap input, water, is used inefficiently or even wastefully. The extent to which such practices have substantive real cost implications is dependent in turn on the extent to which actual water charges differ from the scarcity value of water and the effect of inexact demand elasticities in determining these costs.

4.0 IMPLICATIONS

Demand elasticity is crucial in quantifying policy prescriptions. The qualitative (directional) nature of policy can usually be determined, but absent demand elasticities, efforts to achieve target conservation goals must rely on trial and error, a potentially costly approach both in terms of real costs and foregone benefits. Policy setting by trial and error may also try the patience of the general public. Demand elasticities can be used to quantify policy as follows: suppose the current water charge is \$1.00 per unit (748 gallons),³¹ current aggregate use is 1000 units per month, and a 20 percent reduction in use is targeted. We evaluate the range of quantitative policy options by considering the flat price that will achieve this conservation goal under alternative assumptions concerning the numerical magnitude of water demand elasticity.

The empirical own-price elasticity estimates presented in Tables 1 and 2 range from -0.11^{32} to -1.588^{33} with an average value of -0.49 , which

31. This yields a per gallon price of 0.00133, in the low range of currently observed market prices.

32. Nieswiadomy, *supra* note 14, at 613.

33. Hewitt & Haneman, *supra* note 22, at 188.

is consistent with the average found by Espey et al.³⁴ Table 4 presents the price change, under each of these elasticity measures, necessary to achieve the 20 percent reduction. As can be seen, the required increase in price is 13 percent, 39 percent, or 182 percent, depending on which estimate is used for policy formulation. The price adjustment ranges from negligible to moderately significant to bordering on onerous in some cases.

Two observations are relevant. First, if the demand elasticity is incorrect, the conservation goal may be far from realized. However, a subtler problem is that even when the demand elasticity is correctly estimated, say at an elasticity equal to -0.11 , a policy attempting to achieve the 20 percent reduction in water use based on this estimate implicitly assumes that this price elasticity is valid over the entire range of prices required for attaining the specified reduction. Unfortunately, the range of prices over which these elasticities are estimated is much smaller than the implied policy range. Thus, there is no guarantee that a policy based on the correct elasticity vis-à-vis current and historical use will achieve the proposed conservation goal. Failure to achieve the conservation goal may result in immediate welfare losses, further delay of the conservation goal with attendant opportunity costs and possible irreversible damage to supply, and loss of consumer support for the policy-making agency. Moreover to the extent that there are significant price movements required to attain conservation goals, pricing policies may have political ramifications as well.

TABLE 4: REQUIRED PRICE CHANGES FOR 20% CONSERVATION

Elasticity	Beginning Price	New Price	Percent Change
-0.11	\$1.00	\$2.82	182%
-0.49	\$1.00	\$1.41	41%
-1.59	\$1.00	\$1.13	13%

5.0 CONCEPTUAL ISSUES AND POLICY

Strictly speaking, decision making in the context of a depletable resource is conceptually congruent with the usual "competitive" environment where there are no constraints on resource availability. If

34. Molly Espey, James A. Espey, & William D. Shaw, *Price Elasticity of Residential Demand for Water: A Meta-Analysis*, 33 WATER RESOURCES RES. 1369, 1370 (1997).

consumers maximize utility subject to their budget constraints, firms maximize profits, and markets clear, then the first theorem of welfare economics assures that the competitive equilibrium is socially optimal. However, with either ubiquitous or depletable resources, there is a caveat stipulating the conditions under which this result holds. These conditions preclude "market failure," which occurs in the presence of (i) market imperfections, (ii) asymmetric information, (iii) externalities, or (iv) public goods. In most cases, the conditions listed above can be interpreted as emanating from incompletely defined entitlements (property rights).³⁵ In the case of imminent interest, water is publicly provided, ostensibly due to scale economies (natural monopoly). Water pricing is potentially subject to market imperfections, but the imperfections are manifested in a somewhat unanticipated manner. In the case of a natural monopoly, marginal cost pricing is an efficient pricing policy, but, as is well known, practical problems often suggest that average cost pricing be used as a second best policy approach. When water is abundant, the average cost tends to approximate marginal cost. The use of average cost pricing leads to a close approximation of efficient water allocation, *ceteris paribus*. However, in the case of western water, an additional factor enters the pricing calculus. The element is the user or opportunity cost of water—essentially the present value of current water in the best possible future uses. User cost is then a wedge that separates de facto water charges, based only on production and delivery costs, from *efficient* water charges. Alternatively, so-called "cost recovery based" water charges tend to include out-of-pocket and implicit costs but ignore opportunity costs.³⁶

In the case of depletable natural resources, the social optimum is characterized the same way as in a classical competitive case. Of particular interest is the condition that firms equate marginal revenue (MR) and marginal costs (MC) in satisfying the requisite optimality conditions. This condition holds for the resource user as well, but the requirement is subtler than in the classical competitive equilibrium. Normally the condition is interpreted requiring the equality of marginal revenue and marginal production costs (MPC). However, when a resource is fixed in supply, there is an additional implicit or opportunity cost associated with resource use.

35. The Coase Theorem states that if transaction costs are negligible, the social optimum will be obtained regardless of the assignment of property rights. In practice, however, this condition is rarely met, so the Coase theorem remains primarily an enlightening but unlikely panacea. See Ronald H. Coase, *The Problem of Social Cost*, 3 J. L. & ECON. 1 (1960).

36. This is not surprising as the costs included in water charges are "accounting" costs while the omitted user cost is a less easily quantified opportunity cost. Parenthetically, we anticipate a bit and observe that there are some questions as to the extent that implicit costs (e.g., depreciation costs) are fully and uniformly included.

This element of cost has been designated "user cost"³⁷ and marginal user cost (MUC) is the discounted present value of assigning an incremental unit of the good to its most valuable future use. This, accompanied by additional restrictions, leads to the familiar "Hotelling Rule," that in the case of a competitive market and zero production and stock costs price increases exponentially at the "market" rate of interest.³⁸

The relevance of the Hotelling rule is that there is a divergence between the marginal cost of production and price so that unless one includes marginal user (opportunity) cost in the pricing rule, the usual price equal to marginal (production) cost rule does *not* lead to efficient resource pricing. If resource ownership is well defined, then this is not problematic—the resource owner will include opportunity cost in the efficient pricing of resources.³⁹

In the case of urban-residential water, resource ownership is normally well defined. As previously indicated, however, urban-residential water is usually priced on some type of a cost recovery basis. In the simplest case, this is tantamount to average cost pricing. Since municipal water supply is normally considered a decreasing average cost industry, average cost pricing may be thought to be a good approximation to marginal cost pricing ($P = MC =$ marginal production cost) for larger scale operations and/or as scale economies tend to be exhausted. In other words, once the industry approaches capacity, it may be approximated by a constant cost industry with $AC = MC$; see Figure 2. Also shown in Figure 2 is the addition of marginal user cost to marginal production cost.

Initially it may seem that the identification of marginal user cost, as in Figure 2, would at least lead to partial closure in the effort to quantify the appropriate water conservation policy. That is, even though the demand function in the range of the scarcity value of water may not be known, at least now, with an estimate of marginal user cost, it would appear that some sort of convergence to optimal policy is in progress. This is not the case. Marginal user cost, which equates to the scarcity value or opportunity cost, is directly related to demand. It is that offset between the price of a unit of water and the marginal production cost for that unit that maximizes social welfare across all production periods. Thus, marginal user cost *cannot* be defined independently of demand.⁴⁰

37. This is attributed to Lewis C. Gray, *Rent Under the Assumption of Exhaustibility*, 28 Q. J. ECON. 466 (1914); see Anthony T. Scott, *The Theory of the Mine Under Conditions of Certainty*, in *EXTRACTIVE RESOURCES AND TAXATION* 25 (Mason Gaffney ed., 1967) for an intuitive rendition.

38. A further discussion of user cost is offered in the Appendix.

39. See William D. Schulze, *The Optimal Use of Non-Renewable Resources: The Theory of Extraction*, 1 J. ENVTL. ECON. & MGMT. 53, 61-63 (1974).

40. The tie between the two is explained in the Appendix.

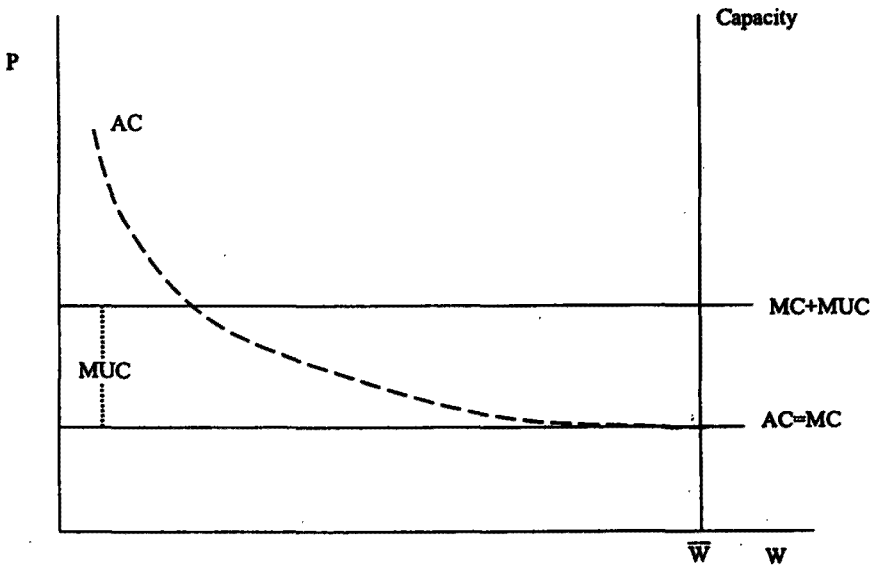


FIGURE 2: AVERAGE AND MARGINAL PRODUCTION COST IN A DECLINING COST INDUSTRY

The impact of this phenomenon is shown heuristically in Figure 3, which depicts two alternative demands for urban residential water drawn, reflecting uncertainty concerning the true demand function due to data unavailability and conflicting elasticity information observed above. However, both demands are drawn to be consistent with cost recovery at a price of P_0 , which does not include a scarcity value, and a consumption level of W_0 . There is a unique marginal user cost associated with each demand curve, which will result in a unique optimal price and quantity. In the case of D_1 , the marginal user cost is equal to the difference between P_1^T and P_0 . The optimal price and quantity combination is P_1^T and W_1^T . Similarly, for D_2 , marginal user cost is the difference between P_2^T and P_0 , with the optimal price quantity combination of P_2^T and W_2^T . Thus, conservation goals and prices sufficient to attain those goals cannot be determined independently. In Figure 3, if a conservation goal was to be lower consumption from the initial consumption level, W_0 , to the optimal consumption level, the target levels would have to be determined as the demand function requires. Furthermore, for optimal conservation goals to be enunciated scarcity values must be included, which requires reliable demand estimates.

A more subtle point is that errors in estimating demand may compound policy oversights. This is also evident in Figure 3. Suppose the

demand estimate of D1 is employed, when D2 is the true demand. Assume the conservation goal is to reduce use from W_0 to \hat{W}_1 , hence a price of P_2^T is chosen. This leads to a false conservation goal of W_2^T . Thus, the pricing rule results in "over" conservation. Similarly, an employed demand estimate of D2, with a conservation goal of \hat{W}_2 (which should be accomplished with a P_1^T price) when D1 is true demand, results in W_2^T consumption. The conservation goal is not met.

Ultimately both the target level of pumping and the price (marginal production cost plus marginal user cost) of water must be determined simultaneously with relevant demand (function) estimates. Since the marginal user cost of water is the discounted present value of the best-forgone future uses, the future as well as present demand for water is of crucial importance.

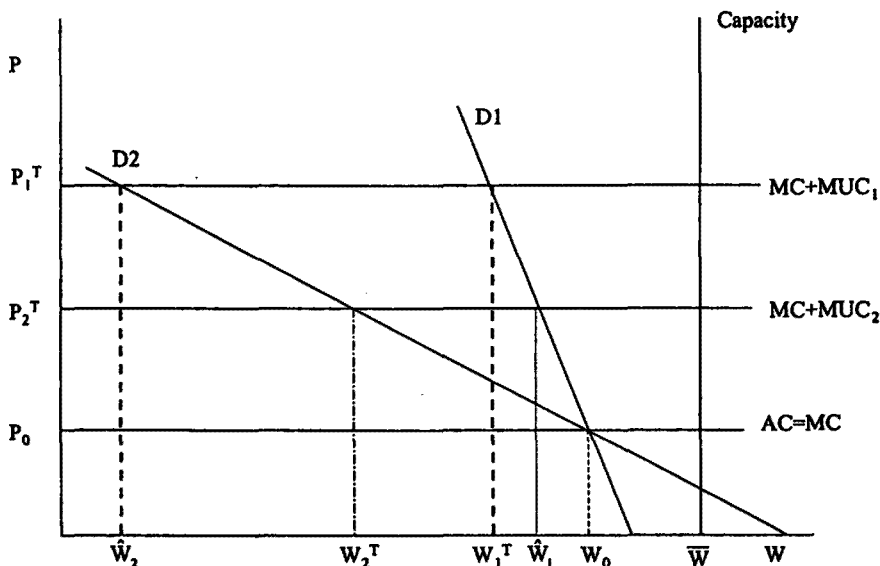


FIGURE 3: MARGINAL USER COST IS DEMAND DEPENDENT

These observations concerning the synergistic relationship between marginal user cost and demand vis-à-vis conservation goals leads to the observation that with population growth there will be non-stationary demand, and this will lead to an increase in the opportunity cost of water, as represented by Figure 4. The marginal user cost of water associated with the initial stationary demand for water, D_s , is less than the marginal user cost associated with the demand after population growth, D_G .

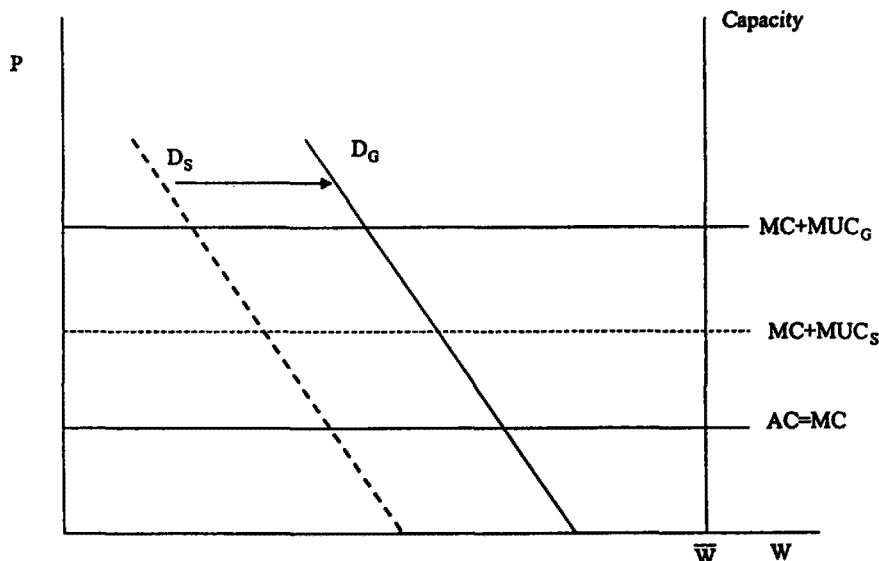


FIGURE 4: GROWTH IN DEMAND AND THE IMPACT ON MARGINAL USER COST

This increase will continue over time; that is, the marginal user cost of water will continually increase from period to period, as represented by Figure 5. Optimal water pricing consistent with increasing demand, but decreasing per capita consumption over time, will *still* require increasing water charges over time. These price increases will incorporate increasing demand into efficient policy.

Whether it may tend to stifle demand growth is another issue. Not only are reliable demand elasticities for current water usage required, but also the policy maker must have access to reliable estimates of future demand functions, prices, and quantities. This allows user cost, and hence the scarcity value of water, to be estimated, which is a prerequisite to enunciating a plan for water use/conservation. The immediate implication of this observation is that water policy becomes intricately intertwined with implicit or explicit policies for urban-residential growth.⁴¹ Failure to include these considerations in the policy scheme will ultimately lead to seriously flawed policy prescriptions.

41. It is common in the West that (often implicit) policies advocating water conservation are accompanied by (explicit) policies that encourage urban growth. The latter quickly eliminates any possible benefits from the former.

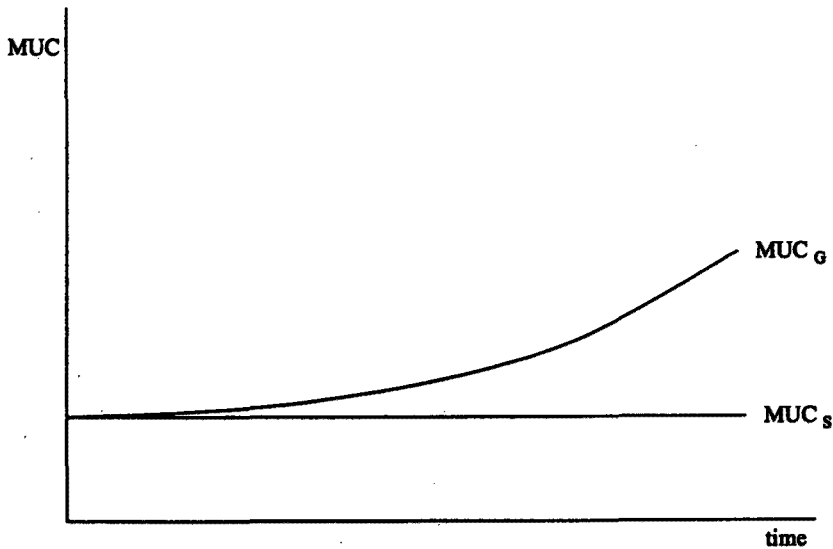


FIGURE 5: MARGINAL USER COST OVER TIME

6.0 THE "REAL" PRICE OF WATER?

The discussion presented in the previous sections begs the question, What is the real price of water? That is, what price should be charged if we fully internalize all relevant costs? Given the currently available information, that answer is well beyond the scope of this study. Indeed, the correct answer is location specific. It also requires a robust demand function that incorporates not only the behavioral aspects of demand but also the appropriate growth (if applicable) of demand over time. However, we can offer a "back of the envelope" static estimate that may provide some insight as well as a bound on a current average price. For the sake of discussion, we assume the average 2001 water price of \$2.30 per thousand gallons (\$0.0023 per gallon) from Section 3 as our starting point. For this to be a true representation of water value it would have to include all tangible costs as well as the user cost of water.

It is estimated, on average, that the current water prices reflect 90 percent of current tangible capital costs.⁴² Completely internalizing current costs would require an increase in this average price to \$2.56.⁴³ At a U.S. House of Representative Subcommittee on Water Resources and Environment hearing on Water Infrastructure Needs, it was estimated that over the next 20 years, \$23 billion annually will be necessary to meet drinking water infrastructure needs.⁴⁴ With the current annual spending of approximately \$11 billion, this leaves an estimated shortfall of almost 46 percent.⁴⁵ Factoring this in, our average water price increases to \$4.26 per thousand gallons. Thus, if a municipality has access to adequate water supplies, that is it does not have to purchase additional supplies, the current average price of \$2.30 per thousand gallons may be approximately half of the actual price, factoring in tangible capital costs.

In addition to the tangible costs, user cost must be considered if the water supply, in whole or in part, is a depletable resource. We showed in Figure 3 that the magnitude of the user cost is demand function dependent. Given our cost estimates that fully internalize capital costs, the previous discussion concerning the robustness of available data with which to estimate demand is germane. Fully incorporating tangible costs into our average water price, results in an average price outside the available data range. Employing existing demand functions introduces a tremendous amount of uncertainty. However, preliminary work of the scarcity value associated with different types demand functions finds that including user cost in the price of water increases the price from 50 percent to more than 150 percent, depending on demand parameters and hydrology.⁴⁶ This means that if the current price of \$2.30 includes all tangible costs, adding user cost would increase the water price by \$1.15 to \$3.45 (total cost \$3.45 to \$5.75) per thousand gallons, depending on the demand function employed.⁴⁷ If the current price reflects 90 percent of total tangible costs, then user cost would range between \$1.25 and \$3.80 per 1000 gallons (total cost \$3.80 to \$6.35), depending on the demand function. Finally,

42. For a discussion of the shortfall between revenues and costs see *Water and Wastewater Infrastructure Needs: Hearing Before the Subcommittee on Fisheries, Wildlife, and Water of the Senate Committee on Environment and Public Works*, 107th Cong. 88-94 (2001) (statement of Janice Beecher, Beecher Policy Research, Inc.).

43. $2.30/x = .90/1.00$ $\Rightarrow x = 2.30/.90 = 2.56$.

44. *Water Infrastructure Needs: Hearing Before the Subcomm. on Water Res. and Env't of the House Comm. on Transp. and Infrastructure*, 107th Cong. 13 (2001) (statement of Rep. J.J. Duncan, Chairman, Subcomm. on Water Res. and Env't).

45. *Id.*

46. Stu Burness & Joe Little, *Municipal Water Conservation Policy: Options and Design*, at 8, Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) Working Paper No. EAR-9876800 (June 2002) (unpublished draft manuscript) (on file with authors).

47. $x = 1.5 \times 2.30$.

internalizing the estimated future capital costs, we estimate user cost for water to be between \$2.10 and \$6.40 (\$6.40 to \$10.65, total cost) per 1000 gallons, depending on the demand function employed. Given these estimates, the current average price of municipal water in the United States may be as low as 22 percent of the real price of water. These results, summarized in Table 5, are meant only as an illustration of the divergence between current prices and real values and should not be used in any analysis. What these estimates do point out, however, is the pressing need for additional research in this area.

TABLE 5: ESTIMATED COST PER THOUSAND GALLONS OF WATER

	Current Average Price	90% Capitalization	Estimated Future Capitalization
Tangible Costs	\$2.30	\$2.55	\$4.25
User Cost	\$1.15 - \$3.45	\$1.25 - \$3.80	\$2.10 - \$6.40
TOTAL	\$3.45 - \$5.75	\$3.80 - \$6.35	\$4.35 - \$10.65

7.0 CONCLUSIONS AND FUTURE DIRECTIONS

The gross estimates presented in Section 6 exemplify the potential problems with which current water policy is made. Prices that are currently charged are not, in many cases, indicative of the total tangible costs, let alone the user cost of the resource. If full tangible and user costs are incorporated into water prices, the efficient current prices should be well outside the range found in any of the empirical demand studies. Future prices that incorporate growth would be even higher. Thus, existing studies of residential and urban water use in the arid Southwest (indeed, in most of the United States) appear inadequate for current and future policy analysis for a number of reasons. First, reported water charges in these analyses are generally based on cost recovery in municipal water supply systems, which fail to reflect the true scarcity value of water. A second, but unique, problem is a direct outcome of the cost recovery pricing methodology. In particular, water charges are, in many cases, so low (less than a tenth of a cent per gallon) that it is unclear whether consumers have the appropriate information with which to make informed decisions concerning water use. This calls into question both the reliability and robustness of elasticity estimates for extrapolating reported demand curves. In fact, it raises questions as to the reliability of the demand estimates themselves. Related to and complicating this phenomenon is the fact that,

in the studies reported, water is considered as an end use commodity. As observed above, there is reason to believe that in many uses water is simply an input in a production process.

For all of these reasons, there is substantial doubt as to the reliability and applicability of extant demand estimates *outside of observed price ranges* as well as substantial doubt as to the efficacy of estimated demand elasticities in extrapolating existing relationships. Moreover, analyses must incorporate the fact that as water charges increase, not only will the quantity of water demanded change, but the patterns of water use will change as well. This means that empirical studies must also allow for structural change in demand functions. Finally, there is the issue of user cost, whose value must be ascertained in order to establish the scarcity value of water. While costs are usually thought of as supply or production related, user cost, the discounted present value of the best foregone use, is clearly demand based; *i.e.*, the value of the best foregone use is determined by the level and nature of future demand.

The analytical value of user cost is as an allocational tool, but its determination involves a Catch-22. While we need current demand and marginal user cost to determine the relevant conservation goals and pricing tools, we also need current and all future demands to determine the relevant (current) marginal user cost. Alternatively, for each time path of water use there is a unique user cost schedule and, in fact, the optimal path of water use is derived from this schedule. However, given the one-to-one mapping between paths of water use and user cost schedules, one must know the optimal time path of water in order to determine the relevant user cost schedule—which in turn is needed to determine the optimal time path of water use. This apparent conundrum is just the usual simultaneity that attends most economic decision making. The problem is intellectually trivial for the theorist, but functionally challenging for the policy maker. This problem is neither novel nor unique. Baumol and Oates make precisely this observation in the context of a discussion concerning the efficacy of Pigouvian taxes.⁴⁸ In our context, the relevance of this observation is that policy cannot be myopic—it must be forward-looking. As a consequence, not only are the informational (as well as computational) demands high, but the incentive structure may be perverse; *i.e.*, to the extent that policy considerations are politically relevant, long-run considerations may be ignored or at least discounted excessively.

More detailed water-pricing data, defined over wider price ranges, is needed. Moreover, the analyses must be undertaken at a more

48. William J. Baumol & Wallace E. Oates, *The Use of Standards and Prices for Protection of the Environment*, 73 SWEDISH J. ECON. 42 (1971).

disaggregated level and should entertain alternative behavioral settings.⁴⁹ While conventional data sources based on historical observations seemingly hold little promise relative to these aspirations, there are several alternative and less conventional methodologies available that could be used to address this problem. One involves the generation of data by conducting pilot projects with alternative pricing scenarios. This option is attractive as it gathers data from actual consumers. The downside to this method is that it is time consuming and hence costly in several senses and may provide only limited information for each pilot.

A second alternative is to employ stated preference methodologies that employ survey techniques.⁵⁰ While surveys do provide a method of gathering data about an individual's willingness to pay under a variety of scenarios relatively quickly and at relatively small costs, the downside is that results may be subject to hypothetical, strategic, and/or other biases.

The third alternative is to use experimental laboratory techniques. Experimental data is gathered by recording participant responses to economic incentives in various decision scenarios. The fact that individuals can incur either economic gains or losses, based on their decisions, purports to limit hypothetical bias.

Each of the methodologies noted above has shortcomings. However, in concert they may provide information sufficient to fill the gaps currently found in residential water demand data. Filling these data gaps and extending the range over which residential water demand is estimated will allow more robust water demand estimates. These estimates will allow more accurate consumer responses to be incorporated into analyses, which, in turn, will result in more accurate estimates of water scarcity values. Better data in general combined with the availability of reasonably accurate scarcity values will allow policy makers to formulate pricing structures that encourage optimal water use in the arid West.⁵¹

49. See, e.g., Janie M. Chermak & Kate Krause, *Individual Response, Information, and Intergenerational Common Pool Problems*, 43 J. ENVTL. ECON. & MGMT. 47 (2002).

50. See, e.g., R.G. CUMMINGS, D. BROOKSHIRE, & W. SCHULTZE, *VALUING ENVIRONMENTAL GOODS: AN ASSESSMENT OF THE CONTINGENT VALUATION METHOD* (1986).

51. For preliminary work in this area specifically related to water see Janie M. Chermak & Kate Krause, *The Impact of Heterogeneous Consumer Response on Water Conservation Goals*, New Mexico Water Resources Res. Institute Technical Completion Report No. 315 (2001); Kate Krause, Janie M. Chermak & David S. Brookshire, *The Demand for Water: Consumer Response to Scarcity and Price*, J. REG. ECON. (forthcoming 2003); see also Jim Henderson & Gary Woodard, *Functioning of Aging Low-Consumption Toilets in Tucson*, Water Resources Res. Center Issues Paper #22, Water Resources Res. Center, Univ. of Arizona (2000) (attempting to gain additional insight into consumer decision making in this context). Henderson and Woodard's methodology involves utilizing "water meters" that allow continuous monitoring of consumer water use. While this approach is still in its infancy, it holds promise for yielding additional disaggregated information regarding consumer water use habits. It is for precisely this reason

APPENDIX: A PRIMER ON USER COST AND SCARCITY

In the simplest analytic case, when the discount rate is zero, optimal resource use requires that marginal revenue equal marginal production cost plus marginal user cost, defined as the value foregone by consuming that marginal unit of the resource today rather than in the future.⁵² Efficient resource use requires that marginal revenue equals marginal cost; the definition of marginal cost has been expanded to account for the fact that the resource is in fixed supply. Since the discount rate is assumed to be zero for this exposition, if demand and costs are stationary, marginal user cost is equal in all time periods.

To illustrate, suppose a competitive firm's revenue function is $R = 100Q - Q^2$, production costs are zero, the discount rate is zero, and the firm has $S_1 = 80$ units of the resource Q to utilize over two periods. Since production costs are zero, profits equal revenues.⁵³ If the firm sets $MR = 100 - 2Q = 0$, then $Q_1 = 50$ units in the first period and $R_1 = \$2500$. By default, $Q_2 = 30$, and $R_2 = \$2100$ so that the sum of first and second period profits equals \$4600.

The marginal revenue or value of marginal product, VMP (since the firm is a price taker), is $VMP_i = 100 - 2Q_i$ for both periods ($i = 1, 2$). Therefore an additional unit of resource used in period 1 has a marginal user cost (MUC_1) of $VMP_2(30) = \$40$, as the best (and *only*) alternative use of the first period resource is in the second period. Thus definitionally, $MUC_1 = VMP_2$. Similarly, $MUC_2 = VMP_1(50) = \$0$.

Alternatively, suppose that the resource is utilized equally between the two periods, so that $Q_1 = Q_2 = 40$. Thus, $VMP_1 = VMP_2 = 20$ so that $MUC_1 = MUC_2 = 20$. The necessary conditions for optimality are normally written as $VMP_i = MUC$ for all t . For our example, it is easy to verify that total profits are \$4800 and any deviation from this allocation leads to a reduction in aggregate profits.

However, the more relevant point to examine here concerns the relationship between resource "scarcity" and user cost. To illustrate this,

that the approach is interesting—it potentially can aid in understanding the role of water prices relative to the many water-based goods and services that consumers produce for their own personal consumption.

52. This does not imply that the choice of the appropriate discount rate is ever simple. The choices often depend on the contextual setting.

53. Since user costs are opportunity costs, they do not enter into the profit calculation. Like "shadow values," they are merely an allocation tool. See Stu Burness & Janie M. Chermak, *User Cost: Real or Illusionary* (1998) (unpublished working paper) (on file with authors). Additionally, while we consider only the resource owners side of the market, extending the analysis to include consumer surplus measures supports the argument.

suppose in the example above the resource stock is $S_2 = 120$. Clearly, $Q_1 = Q_2 = 50$, with aggregate profits equal to \$5000. More relevantly, observe that since $VMP = 0$ in both periods, likewise $MUC = 0$ in both periods. Alternatively, if $S = 40$, and $Q_1 = Q_2 = 20$, then it is easy to verify that $VMP_i = MUC_i = 60$, $i = 1, 2$. Thus, MUC increases with resource scarcity and in fact is an accepted measure of resource scarcity.⁵⁴ For the general case of T periods where the discount rate is not zero, the condition for optimal resource allocation generalizes to $VMP_t = (1+r)^{t-s} MUC_s$ for $s, t = 0, 1, \dots, T$ and $s < t$. This tends to bias resource use toward the present—the larger the discount rate the greater the bias. Moreover the presence of stock effects will generally lead to an MUC that changes over time as the resource stock changes. None-the-less, the basic result still holds.

54. See TOM H. TIETENBERG, ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS 90 (5th ed., 2000).