College of Agriculture and Natural Resources
Department of Food and Resource Economics

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The Conservation of Residential Water

Scarcity Pricing of Water in Northern New Castle County[1]

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It is difficult to overstate the importance of a reliable water supply. Each day residents access high quality water with little thought about its broader availability. Engineers have made tremendous gains in maximizing the supply available at any given time, and yet water remains an essentially fixed resource. Water scarcity pricing may lessen the strain put on existing supply by expanding populations and increased surburbanization, but it is only one part of a sustainable solution. Effective water management requires pricing for conservation to be used in combination with supply-side efforts. This report suggests how reductions in residential water consumption might be achieved by varying price to reflect scarcity.

Photo by Jonathan Cox

When price changes to reflect scarcity, demand matches supply. During droughts, a relatively high price signals consumers that it is time to conserve. Such an incentive is important even though water is an essential good. Consumers are accustomed to scarcity pricing for other special goods, including food and gasoline. With the appropriate protections for low-income consumers, scarcity pricing ensures that no one wastes water during droughts.

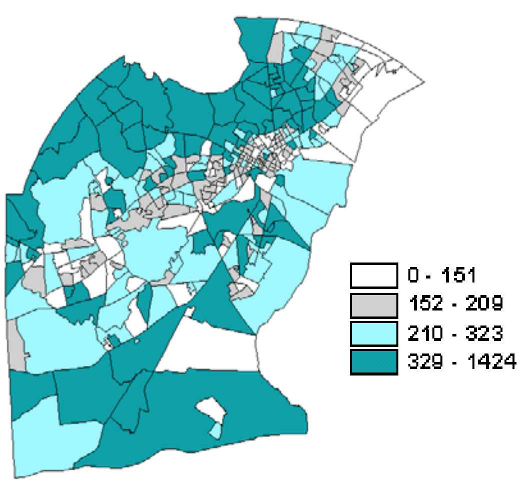

Figure 1: Summer Household Water Use (gallons per day)

Figure 1 shows average summer household water use by Census block group in northern New Castle County (NNCC). Periods of high residential water consumption tend to coincide with the hottest and driest weather. The increase in summer residential consumption is often due to outdoor uses, including lawn and garden watering, swimming pools, and car washings. Although these uses are valuable, they are not typically considered to be as critical as those gallons used for drinking or bathing. One of the principal benefits of pricing water for conservation is that it lets *people* decide the value of each of their many water uses. If someone wants to conserve during times of drought, his or her water bill will be lower than it otherwise would be. If residents need to water their recently planted landscaping, then they can—they just pay a "premium" for using outdoor water during droughts.

The current system, in contrast, offers confusing signals when droughts occur but price remains fixed. Simultaneously, consumers have an incentive to overconsume water—because its cost is below the market value of the resource—while governments are calling for conservation. Governments may request voluntary reductions or, in severe droughts, mandatory restrictions on outdoor use. After a drought, consumers may face higher prices—though water is plentiful—so suppliers can recover from losses incurred during the drought. When scarcity pricing is not used, consumption is encouraged when it should be discouraged and discouraged when it should not be.

Is Pricing Water Fair?

The fairness of scarcity pricing comes from how it allows consumers the freedom to make their own consumption choices when water is scarce. Pricing is often misconceived as being unfair to people of limited income. This criticism only holds when a well-designed threshold, which acts to protect critical uses of water, does not accompany pricing. With a threshold pricing targets less-valued uses, including outdoor watering and leaky toilets. Nevertheless, pricing only works to the extent that the demand for essential uses of water can be met. If essential indoor water uses must be targeted to overcome droughts, then the problem is an inadequate supply, requiring non-pricing solutions.

THRESHOLD

Thresholds protect essential uses of water—including drinking, bathing, and cooking—from price increases. Consumption under a threshold is charged a low, fixed price. Uses, which are critical to basic needs, ought not be targeted for conservation. Above a threshold, however, the unit price of water can increase to encourage conservation in times of drought.

Setting the threshold is a political decision, but it should be tied to an average household's essential uses. If the threshold is set too low, then some essential uses will be subjected to increased prices. This seems inequitable to low-income consumers. If the threshold is set too high, then very high price increases will be needed to achieve conservation goals. From an efficiency standpoint, however, pricing will achieve conservation goals regardless of where the threshold is set.

The threshold addresses fairness considerations. The variations in water usage among similar households (same number of people, property size, and income) mainly arise from outdoor activities. Outdoor uses are important, but are subject to behavior of a more discretionary nature and are highly sensitive to weather. For instance, our application for NNCC of the Opitz et al. (1998) model predicts a 47 percent increase in consumption when the temperature and rainfall values simulate typical summer drought conditions rather than average summer conditions. Though some of this increase in predicted consumption would come from essential activities, most of it likely arises from outdoor uses of water.

Some may argue that a fixed threshold is unfair to households with many occupants or with extraordinary outdoor watering demands. The political process has the ability to establish more complex thresholds than are presented in this document. One alternative method is choosing a threshold based on historical household consumption from a previous winter period, when discretionary uses are at their minimum.

Why Scarcity Pricing of Water Is Efficient

When water is plentiful, there is little reason to conserve. But as water becomes scarcer, its value increases. The value of water during droughts is the price that water would command in a competitive market. This value exists despite the fact that water is typically supplied in urban residential areas by natural monopolies at an inflexible unit cost. A more efficient allocation occurs if consumers are allowed to respond to the true costs of their behavior.

ELASTICITY

Price elasticity, i.e., consumer responsiveness to price change, is the most important aspect of water pricing for conservation. Studies indicate the response to price change varies from $e=-0.25$ to $e=-1.0$. A price elasticity of –0.25 means that a 1 percent increase in price will result in a 0.25 percent decrease in consumption. As price elasticity becomes more negative, residents are assumed to be more responsive to price changes. Elasticity is most accurate for small changes in price.

Consumer responsiveness to price change is captured in a measure known as price elasticity. People will respond to price changes for water even though it is used daily and billed infrequently. Because uses for water vary from drinking to bathing to watering yard plants, determining a single price elasticity for all water use is complicated. When price increases, people are less responsive in their drinking or bathing choices and more responsive in repairing leaks and watering lawns. Social efficiency arises when the highest-valued uses of water are met. This occurs when individuals make optimal water consumption decisions in their own best interest, bearing fully the costs of their actions. This result applies whether or not there is a threshold.

Analysis of Conservation Pricing

Although mandatory restrictions[3] and rationing[4] are widely used to conserve water during droughts, only pricing efficiently signals water scarcity. The importance of conservation is not clearly conveyed with restrictions and rationing because the price of water remains artificially low. Conservation pricing, however, is flexible. Droughts can end abruptly and so can the price premium. Conservation pricing provides a clear incentive to consumers, which rewards those who conserve, but which also allows people to use nonessential water as long as they are willing to pay for it.

In the analysis that follows, the Opitz et al. (1998) model is modified to predict residential water consumption in NNCC subject to varying thresholds, elasticities, and drought conditions. The Optiz et al. (1998) model is adapted using demographic and consumption data from NNCC. Details of the analytical techniques are provided in the appendix.

Application 1—How Prices Change with Deficit

"Deficit" measures the percentage of demand that cannot be met during a drought. Price increases in this circumstance act as an incentive to reduce consumption so that demand comes back into line with supply. Figure 2 shows how price increases for various deficit levels, assuming that there is no threshold (all consumption levels are subjected to the higher price level). This assumption is relaxed in Application 4.

Figure 2 shows that the larger the deficit, the higher the price increase, which provides the efficient signal when water is scarce. This scarcity price increases at an increasing rate with deficit. Various assumptions on consumer responsiveness are also presented. The more responsive people are to price change, the lower the price increase required to overcome the same deficit. For instance, when consumers are highly responsive (e=-1.0), doubling the price of water decreases consumption by approximately 50 percent. If consumers are unresponsive, then this same price change only reduces consumption by approximately 16 percent.

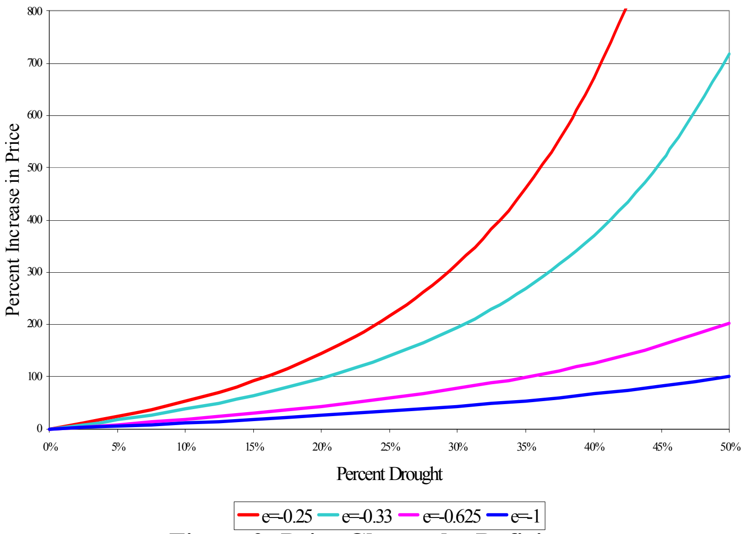

Figure 2: Price Change by Deficit

Application 2—How Price Changes with Threshold
This application assumes a deficit of 15 percent and thresholds varying from 0 to 150 gallons per day. As the threshold increases, the amount of water available for conservation pricing decreases. Thus, higher thresholds require higher price increases to accommodate the 15 percent deficit. Also, the more responsive residents are to increasing price, the less the price needs to increase. A price increase of 150 percent will account for a 15 percent deficit for all but the lowest level of responsiveness. In numbers, the average household would reduce its water consumption by 15 percent when the price changes from $3 per thousand gallons to $7.50 per thousand gallons, for consumption above the 150 gallons per day threshold.

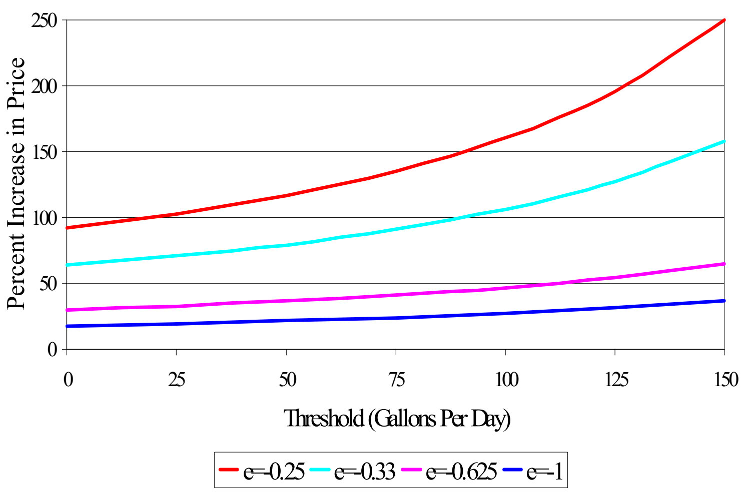

Figure 3: Price Changes by Threshold

Application 3—How Price Changes with Responsiveness
Figure 4 assumes a 15 percent deficit and a threshold of 150 gallons per day to study how price changes with consumer responsiveness. The results are presented by supplier. As responsiveness decreases, a greater price increase is required to achieve the desired reductions. On average, the residents supplied by the City of New Castle consume the least per household. Because less water is available for conservation pricing, City of New Castle residents are predicted to be less responsive overall.

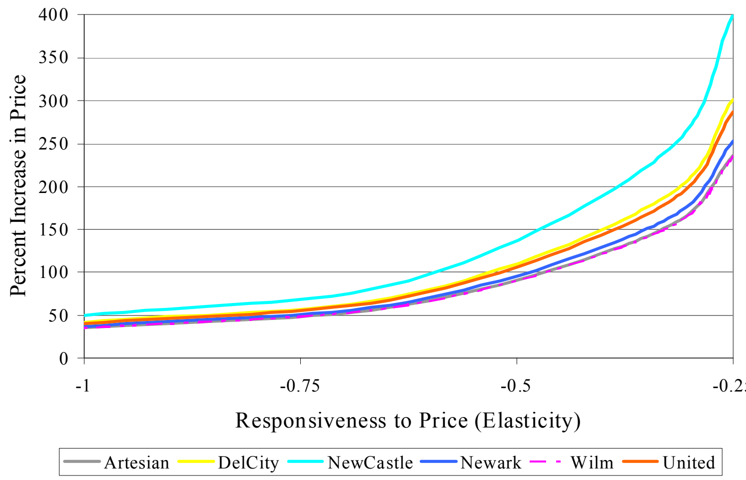

Figure 4: Price Change by Elasticity

Application 4—Varying Threshold, Elasticity, and Deficit
Figure 5 varies threshold, elasticity, and deficit at the same time. To do this, it is assumed that consumer responsiveness is either responsive (-1.0) or unresponsive (-0.25). The threshold is set at 100 or 150 gallons per day. Finally, the results are aggregated by accounting for each supplier's portion of NNCC consumption. Details on consumption by supplier and the weighting procedure are presented in table 1. Figure 5 shows the extreme variation between the two levels of consumer responsiveness. If consumers are unresponsive, they require a significant increase in price to overcome mild and extreme droughts. However, if consumers are responsive, a much smaller price increase overcomes most deficits. The higher the threshold, the less water is available for conservation pricing. As a result, a higher price increase is required to overcome the same deficit.

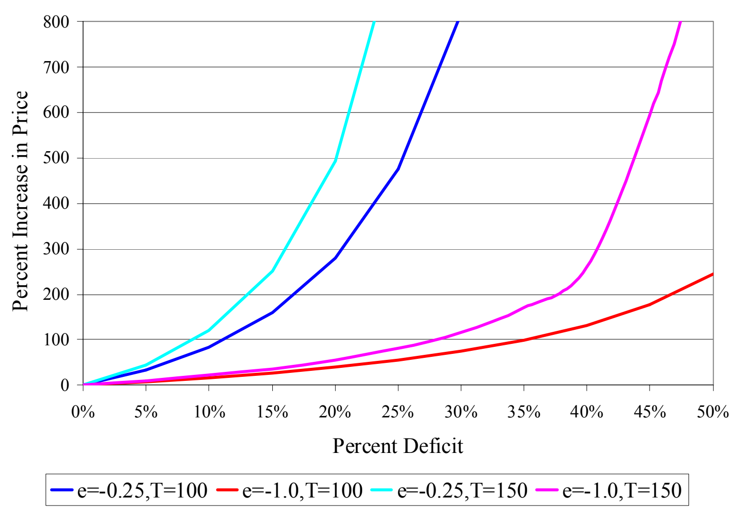

Figure 5: Price Change by Threshold, Elasticity, & Deficit

Table 1: Average Household Consumption by Supplier

Supplier	HH*	Price per 1000 gallons ($)	Summer HH Cons. (gpd)	Predicted HH Drought Cons. (gpd)	Supplier Summer Cons. (%)
Artesian	60,340	3.55	239	351	39.0
Delaware City	732	2.05	208	307	0.4
New Castle City	2,153	3.08	186	274	1.1
Newark	12,660	2.46	229	337	7.8
Wilmington	45,970	2.19	240	354	29.9
United	37,538	2.58	213	314	21.7

Source: 1990 U.S. Census and Delaware Water Resources Agency
*HH=households

Implications

As long as a controlled price of water allows demand to exceed supply, reducing consumption will remain an important part of water supply management. Based on current demographic data, water conservation pricing in NNCC offers one method of efficiently and fairly reducing consumption.

Apprehension about conservation pricing typically centers on uncertainty about consumer response. This report seeks to improve information about likely consumer responses to price change, by varying thresholds, responsiveness, and deficit levels. Upper and lower bounds on consumer behavior are offered. Importantly, increased public awareness and education can only help improve conservation efforts.

Analytical Appendix

This appendix describes how the Opitz et al. (1998) model was adapted to predict residential water consumption in NNCC and how the analytical applications were derived. An earlier version of this model was presented in Ehemann, Duke, and Mackenzie (2001). The Opitz et al. (1998) model is applied to the locality of interest by using demographic and consumption data to calculate a supplier-specific constant, alpha. Specifically, block-group Census data on income, people per household, and households per acre are converted using GIS to the supplier level by weighting each variable by the proportion of households they represent. The temperature and rainfall variables are assumed to be constant across supplier area. This analysis averages 1998, non-drought-year values for Newark and Wilmington's maximum temperature (80.5 degrees) and rainfall (6.14 inches) for the three-month period, July through September, provided by the Center for Climatic Research at the University of Delaware.[5]

The supplier-constant alpha values are derived for each supplier based on varying elasticity (-0.25, -0.33, -0.625, and –1.0) in the model below. The average quarterly consumption can be calculated at the supplier level for the four elasticities. In order to simulate drought conditions, weather variables were altered to represent July 1999—a hot and dry month. Averaging the values for Newark and Wilmington from the Center for Climatic Research produces a maximum daily temperature of 92.4 degrees and rainfall of 0.72 inches.

The summer (drought) quarterly quantities—representing the average household quarterly consumption for each supplier—are calculated as follows. The Opitz et al. (1998) model is used to predict summer residential consumption:

$$Q_S = \alpha_s I^{b_1} H^{b_2} L^{b_3} T^{b_4} R^{b_5} P^{b_6} e^{b_7 B}$$

where:

α_s = supplier-specific intercept
$I_s b_1$ = Median Income
$H_s b_2$ = People per household
$L_s b_3$ = Density
T = average temperature
R = average rainfall
P_s = marginal price of water
B_s = fixed charges

This formula was manipulated for the analysis. First, define a scalar of supplier-specific attributes, $X_s = I_s^{b_1} H_s^{b_2} L_s^{b_3} e^{b_7 B_s}$, and let countywide weather, Y, be defined as the 1998 values above. Price elasticity takes on four values: b_6 = -0.25, -0.33, -0.625, and –1.0. Now, the model can be rewritten to predict summer demand during a hot-and-dry drought, $Z_s = \alpha_s X_s Y` P_s^{b6}$, where Y' are drought rain and temperature variables. Define a factor, ρ, which changes price and a threshold, T. A deficit variable, γ, captures the percent of demand met during a deficit. Then, this model can be solved for the price change:

$$\gamma Z_s = \left(1 - \frac{T}{Z_s}\right)\left(\alpha_s X_s Y`(\rho P)^{b_6}\right) + T \Rightarrow \rho = \left(\frac{\gamma Z_s - T}{Z_s - T}\right)^{\frac{1}{b_6}}$$

Works Cited

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[3] One way to reduce demand is by restricting certain uses of water. Delaware has used mandatory restrictions to reduce demand during times of drought. These restrictions prohibit outdoor uses, such as watering lawns, washing cars, and filling swimming pools. This method seemingly targets less-essential consumption during a peak demand and raises awareness. However, the enforcement costs and effectiveness, associated with policing and fining those not in compliance, must be considered. Mandatory restrictions also create no incentive take further steps to reduce less-valued uses—i.e., fixing leaky toilets—nor do they allow for potentially valuable uses of outdoor water—expensive landscaping cannot be watered.

[4] Rationing water shuts off water to consumers for a period of time. Rationing accomplishes the necessary reduction in consumption with certainty. However, rationing is unpopular because it prohibits even essential uses when the water is off.

[5] Website: http://www.udel.edu/leathers, accessed November 2001.