April 2001 FREC RR01-04

A Spatial Analysis of the Distributional Effects of Water Quantity Management

Robert W. Ehemann
Joshua M. Duke
John Mackenzie

FOOD & RESOURCE ECONOMICS

FREC Research Reports

Department of Food and Resource Economics • College of Agriculture and Natural Resources • University of Delaware

A Spatial Analysis of the Distributional Effects of Water Quantity Management*

Robert W. Ehemann

Joshua M. Duke

John Mackenzie**

Food and Resource Economics

University of Delaware

205 Townsend Hall

Newark, DE 19717-1303

*Funding from the Delaware Water Resources Council supported this research. We have benefited from the assistance of Delaware Water Resources Agency.

**Authors are Undergraduate Research Assistant, Assistant Professor, and Associate Professor in the Department of Food and Resource Economics, University of Delaware. Duke is the corresponding author.

Water supply managers in growing areas must address increasing demand for an essentially fixed, though highly variable, resource. This worldwide problem inevitably arises as demand increases with population and standards of living (Loucks 1999, Mayor 1997). Currently, 505 million people live in water-scarce or water-stressed conditions, and this number could rise to 3.2 billion people by the year 2025 (Dunphy 2000). Water-stressed locations are not necessarily arid regions of the world. Nonporous materials in urban and suburban areas prevent rainwater from percolating through the soil. Excess water becomes runoff, which erodes riverbeds, prevents groundwater recharge, and exacerbates water supply issues. Spatially, suburban growth distributes the demand for water over a greater area. Water delivery requires increasingly more infrastructure, including holding tanks, reservoirs, treatment plants, and pumping stations. At the very least, suburban growth adds miles of new piping to the system and requires a tremendous amount of water to keep the lines full. This paper investigates the relationship between the spatial distribution of the residential population and residential water demand. Specifically, three water quantity management strategies are compared in times of deficit.

Conservation is the root of demand-side management. However, conservation has many interpretations. Chesnutt and Beecher (1998) describe ecological, hydrological, traditional-economic, and resource-economic perspectives on conservation. The ecological perspective emphasizes ethical constraints to avoid the consequences of over consuming in a common property setting. The hydrological perspective focuses on the water cycle and engineering solutions to maintain water supply. Water allocation efficiency through pricing guides the traditional-economic perspective, while the resource-economic perspective merges a sustainability criterion with the traditional perspective. Any attempt to implement water management policy will undoubtedly satisfy those with one perspective and offend others. For instance, objections to the use of price arise from those who see it as insufficiently addressing ethical or supply concerns. This paper attempts to address such concerns by examining the distributional and supply impacts on residents when water scarcity pricing is implemented.

In the next section, this paper outlines many of the demand-side management techniques. An empirical model is then constructed to investigate three common management techniques: (1) pricing; (2) rationing; and (3) mandatory restrictions applied to large residential lots. The third section describes the data collected on residential users in northern New Castle County, Delaware. The results are presented in section IV and a final section interprets the results and draws conclusions.

I. Demand-Side Management of Water Quantity

Demand-side management policies may be distinguished by whether they use price to signal the relative scarcity of water. Nonprice approaches include voluntary conservation, mandatory conservation, feedback, home auditing, restrictions, rationing, and leak detection. Price-based approaches include efficient pricing, water alerts, seasonal pricing, increasing block rates, and excessive-use charges.

Nonpricing Approaches

Voluntary conservation approaches are politically expedient because they do not force any person to alter his or her behavior. These approaches rely on an ecological ethic in that they attempt to signal and educate residential users that it is necessary to conserve. In times of deficit, voluntary conservation is requested in a governmental announcement, which signals residents to reduce consumption. Other voluntary approaches include feedback and home auditing, which help residential users better understand their water consumption behavior.

An illustration of the feedback technique occurred in Melbourne, Australia (Aitken, et al. 1994). Three levels of information were given to residents about their personal water consumption over a nine-week period: (1) no feedback; (2) feedback on personal water consumption; and (3) feedback to a "dissonance" group. A weekly postcard was sent, stating the household's water use and the average consumption for similar households. However, the average for similar households was artificially reduced by 10 percent. Even with the inaccurate comparative consumption values and frequent reminders, consumers did not significantly reduce consumption. Alone, frequent consumption information may not be an effective conservation method.

Home auditing is similar to feedback in that both methods rely on education and awareness to promote conservation. One application of home auditing was implemented in the suburban area of Novato, California, where residential customers account for 85 percent of water use (Nelson 1992). Single-family detached homes within the upper quartile of residential water use were audited, which revealed that this target group used 41 percent more water than the average single-family detached home for the service area. The audit included fixing leaks, replacing showerheads, adding toilet tank displacement devices, evaluating lawn irrigation practices, and recommending irrigation schedules. The program resulted in a 15.5 percent reduction in water use for program participants.

Large consumers of water have a greater potential for reducing consumption on the margin, but home auditing may be less effective when applied to the entire residential sector.

Water suppliers tend to turn to mandatory restrictions if voluntary conservation fails. Mandatory conservation measures may take several forms, which are distinguished by the time at which they are implemented. Ex ante restrictions implement water conservation measures prior to the occurrence of a deficit. For instance, in Tucson, Arizona, a desert landscaping program provides incentives to residents who replace their grass lawns with native plants not requiring water beyond that which is naturally supplied (Cuthbert 1989). Other types of ex ante restrictions are mandatory low-flow toilets and other conservation fixtures. In contrast, ex post restrictions address temporary shortfalls in the supply of water. One popular approach restricts outdoor water use, such as watering lawns and washing cars. Importantly, conservation gains from mandatory restrictions must be balanced with new enforcement costs and the rather indiscriminate costs imposed on residents, such as the loss of valuable landscaping plants.

A more severe measure, rationing, typically occurs when mandatory restrictions fail. By constricting the distribution of the water, rationing achieves conservation goals regardless of consumer behavior. In Kingston, Jamaica, water is shut off for several hours per day during deficits (Rosenberg 2000). Similarly, Sao Paulo, Brazil, uses the two-and-one plan: two days with and one day without water during deficits (Lehman 2000). Although the rationing method is a direct way to achieve conservation goals, physically preventing the consumption of water may be extremely unpopular. Moreover, rationing, like mandatory restrictions, seeks to achieve conservation targets without distinguishing high-value uses from low-value uses. As such, these conservation tools inefficiently allocate a scarce resource in an environment with heterogeneous consumers.

Pricing Approaches

Mechanisms for pricing water tend to vary with technical capabilities. Purely efficient pricing requires that the price of water be able to change instantaneously to reflect the relative scarcity of the resource and that consumers are aware of the price at all times. Since it is currently impractical to implement purely efficient pricing, water managers use different methods to capture some of the efficiency gains associated with pricing.

One approach is the increasing block rate. This is a pricing structure that increases the price for water as additional gallons are consumed. For example, the Alameda County Water District in the southeast San Francisco Bay area used a steeply increased block rate structure as a deficit management policy. Households consuming over a threshold of 350 gallons per day were faced with a higher rate (Pint 1999). A study of 599 single-family homes from 1982 to 1992 found that the policy affected the behavior of residents (Pint 1999). Before the policy, 57 percent of the homes had consumption below the daily threshold, compared to 78 percent after the policy was implemented. Seasonal pricing, like block pricing, sets the price of water higher during the periods of high use. Typically, the higher demand for water occurs in the summer as residents are home enjoying their pools, gardens, and lawns—all of which require large amounts of water.

Excess-use charges affect residents who exceed levels of consumption or use water for nonpreferred uses. Gross excess-use charges take the form of a fee for consumption that exceeds a predetermined "appropriate" level. Using the winter as the nonpeak period, the household's monthly baseline usage is determined. This method can provide year-round conservation for the target customers who use some amount above the average usage for residents. De facto impact fees arise in some areas for consumption that is not preferred. In Newark, Delaware, the municipality charges a sewer use fee for all water supplied to each household. As such, water applied to lawns or indoor plants is essentially charged a higher fee than water that uses sewer services.

The water-alert method addresses supply problems with temporary price increases. When the City of Santa Fe cannot meet between 16 and 35 percent of the demand, a 1996 ordinance requires commercial and residential water use to be reduced by 25 percent of their individual usage for that month in the previous year (Tippett and O'Hare 1999). A $10 surcharge for every 1,000 gallons over the 75 percent of the preceding year’s consumption is applied. Further, a surcharge for single-family homes is applied for those in excess of 12,500 gallons per month and a $150 fine is added to the bill of those who show no progress toward the 25 percent reduction after three months. Residential water use dropped by 28 percent as the result of the ordinance. Prior to the ordinance, 25 percent of homes used in excess of 12,500 gallons in August of 1995. After the ordinance was enacted, only 9 percent of the homes consumed in excess of 12,500 gallons (Tippett and O'Hare 1999).

II. Conceptual Model

Pricing water to reflect relative scarcity is an efficient way to allocate water. Because supplying water involves large investment in infrastructure and increasing returns to scale over normal operating ranges, natural monopolies may be technically efficient. Resource allocation efficiency requires there to be appropriate public control of a supplier's price. This section uses previous studies on the price elasticity of water demand to build an empirical model of how residential consumers will respond to changes in price in New Castle County, Delaware.

The Price Elasticity of Residential Water Demand

Water is a special commodity, which endows suppliers with a higher standard of social responsibility. Service reliability, quality, and production cost recovery are critical objectives. When water is in deficit, some of these objectives may not be met and conservation becomes an important tool in helping to meet reliability and cost recovery goals. A price mechanism can either penalize excessive uses or reward conservation efforts. That part of residential water use that is essential to life typically is exempt from conservation policies. But setting the threshold at which "essential" use becomes "nonessential" use is a political issue. Once the threshold is set, it becomes a goal for the cost-effective allocation of water. Scarcity pricing above the threshold achieves that goal efficiently.

Price elasticity of residential water demand is used to measure how consumers change their water consumption in response to changes in price. In a meta-analysis of 24 journal articles published between 1967 and 1993, Espy, Espy, and Shaw (1997) found an average price elasticity of -0.51. Indeed, Cohen and Golub (1996) believe that consumers do not respond as readily to changes in the price of water as to changes in the prices of less-essential commodities because water is viewed either as an unlimited resource or as a "God-given commodity". Moreover, most consumers of water only "see" the price quarterly in contrast to many other commodities where the price is clear at the time of consumption. Some studies have investigated whether consumers are more responsive to price in times of deficit. Renwick and Archibald (1998) collected six years of panel data for 119 single-family households near Santa Barbara, California. Water pricing was in effect for all households in times of deficit. Renwick and Archibald (1998) found that low-density households (0.55 acres and greater) had larger quantity reductions, but the overall price elasticity was -0.33 in the short term and -0.39 in the long term. Renwick and Archibald (1998) also found that low-income families are more responsive to price (-0.53), whereas the moderate- to high-income households were less responsive (-0.22). High-income households were the least responsive to price (-0.11). Nevertheless, large reductions are possible with large price changes. Pint (1999) reports that single-family residential water use in Santa Barbara, California, declined by 62 percent when faced with a 2,800 percent price increase.

An Empirical Model

Pricing requires a reliable forecast to manage a resource effectively, and there are many methods of forecasting water consumption. One forecasting model used throughout the United States by water utility companies is the Institute for Water Resources – Municipal And Industrial Needs (IWR-MAIN), a software program adopted by the U.S. Army Corps of Engineers as a tool for improving water use forecasting. IWR-MAIN is used in many conservation studies because it translates readily available demographic statistics into estimates of current water demands at the spatial, temporal, and sector level. The software also allows the residential, commercial, and manufacturing sectors to be isolated from one another. Opitz et al. (1998) used the IWR-

MAIN software to derive a general formula to forecast average rates of residential consumption, according to the following model:

$$q_{c,s,t} = \alpha I^{\beta 1} H^{\beta 2} L^{\beta 3} T^{\beta 4} R^{\beta 5} P^{\beta 6} e^{b7B} \qquad (1)$$

In equation 1, the quantity demanded $q_{c,s,t}$ is the predicted average water use in sector c during season s in year t. The quantity demanded is a function of an area-specific constant (α), median household income (I), average number of people in a household (H), average housing density in units per acre (L), average maximum daily temperature (T), rainfall (R), marginal price of water, including sewer charges related to water use (P), fixed charge or rate premium (B), and coefficient of the rate premium (b_7). Equation 1 was selected for its flexibility, particularly in deriving a unique intercept for each supplier's service area.

The Analytic Scenarios

Equation 1 provides a conceptual framework for the analysis of three deficit scenarios that test the distributional effects of various water-management strategies. All three scenarios are constructed to reduce summer consumption by 25 percent, thereby simulating conservation during a deficit. Table 1 presents the elasticities used in the log-linear model, equation 1, as adapted to New Castle County.

The first scenario represents water scarcity pricing during times of deficit. In the application to New Castle County, a 25 percent countywide reduction is achieved by increasing the marginal price of water by 591 percent above a threshold. Specifically, each household pays the normal summer rate for the first 48 gallons of water per day (48 gallons is the minimum estimated consumption in the study area and is thus treated as a threshold below which price will not increase). It is assumed that consumers use the winter marginal price elasticity to respond to this initial level of consumption. Any consumption above 48 gallons a day will be priced at a 591 percent increase above nondeficit summer rates. In this scenario, the incentive to conserve varies directly and proportionately with increases in each household's water bill. Consumers are allowed to balance their private costs and benefits on the margin for nonessential water consumption to achieve reductions efficiently.

The second scenario captures rationing. A 25 percent reduction is enforced in every household. This scenario imposes no penalties on inefficient water uses and requires the same reduction from all households. Rationing raises concerns for fairness because urban households with mainly essential uses of water will be forced to reduce consumption at the same rate as households in large-parcel growth areas that merely are reducing their nonessential uses. Utilities that use rationing repeatedly may need to increase the percentage reduction progressively over time as consumers respond by increasing their nondeficit water use in order to augment their deficit allocation.

The third scenario employs a mandatory restriction method to achieve a 25 percent countywide reduction in residential water use by redistributing the burden to households on larger parcels. The reduction achieved in the first two scenarios is now the responsibility of those households with 0.10-acre lot size and larger. The households on smaller parcels are unaffected. This scenario captures the mandatory restrictions on outdoor water use that were actually implemented during the 1999 drought in New Castle

County. The households that bear the burden of reducing tend to be the newer growth areas with the potential to reduce excessive outdoor uses.

These policies also affect suppliers' revenue and profitability in times of deficit. Utilities may attempt to offset deficits by purchasing water from other regional suppliers at high prices. Such behavior mitigates the need to conserve water during droughts, but results in higher prices to consumers during the succeeding nondeficit quarter as suppliers seek cost recovery. Moreover, some utilities may seek higher rates following deficits because of shortfalls in total revenue. As conservation policies, rationing and mandatory restrictions may require these cost-recovery plans, which penalize all consumers during nondeficit periods regardless of their behavior during deficits. In contrast, water-scarcity pricing allows consumers to bear to full cost of their actions during deficits. The extra revenue generated under a pricing scenario can either be used to enhance deficit supply or to reduce rates during nondeficit periods.

III. Data

New Castle County's drought in 1999 provides an empirical setting to study the distributive effects of water conservation through pricing, rationing, and mandatory restrictions. Because it is a fast-growing county with persistent supply problems and because it lacks access to economical sources of groundwater, New Castle County is heavily dependent on the hydrologic cycle. According to Montgomery (2000), New Castle County ranks in the top 4 percent of all counties for population density. The drought of 1999 occurred as a result of deficit rainfall between the fall of 1998 and

August 1999. On 23 July 1999, voluntary restrictions initially reduced consumption by 15 percent, but consumption returned to normal in a few days (Delaware Water Resources Agency 1999). Mandatory restrictions were implemented on 5 August 1999 and remained in place until 8 September 1999. During mandatory restrictions, total consumption remained approximately 15 percent below normal (Delaware Water Resources Agency 1999). The City of Newark was ultimately forced to consider a rationing plan (Barrish 1999). Although heavy rains caused the deficit to end abruptly, at no time did the price of water increase to reflect its scarcity during the drought.

Consumption data are drawn from the northern part of the county, where residents get their water from one of seven suppliers. The Delaware Water Resources Agency provided average daily consumption data for each month of 1998 for each supplier (figure 1). The 1998 data is the most recent nondeficit year available. Winter and summer average daily consumptions were calculated from the three-month averages for January through March and July through September, respectively. The residential share of the total demand for each supplier was computed, using data from a previous study of water consumption in New Castle County (Hurd 1998). It was assumed that the difference between total summer and winter consumption is wholly attributable to residents. Total residential demand data is converted to quarterly household consumption in gallons per quarter per household.

Data were also collected to explain consumption in equation 1. The maximum daily temperatures and rainfall variables for 1998 are measured using data from the WorldClimate (2001) website. Forty-year averages for two stations, one in Newark and the other in Wilmington, were averaged to represent these weather variables for the

County. The same winter and summer value is assumed to apply to every water service area. The marginal price and fixed charge variables are compiled from the Delaware Water Resources Agency (2000). Increasing block rates are used by suppliers, and the marginal price is determined by the average winter and summer household quantities at the supplier level and applied to the corresponding block groups. Only Artesian Water Company uses a method that attempts to distinguish summer and winter in their marginal pricing—an increasing block rate with a threshold of 20,000 gallons per quarter (approximately 220 gallons per day). It was assumed that all fixed charges accruing to residents were based on the typical 5/8-inch piping size.

The income, household size, and housing density variables are measured using 1990 Census block group-level data. The 1990 median income is adjusted by a factor of 1.47 to approximate 1998 incomes. Block group population data from the 1990 Census and 1997 parcel data from the New Castle County Land Use Department determine individuals per parcel, which is used to proxy for individuals per household. Residential parcels are presented in figure 1. There were 159,435 parcels in the 348 blocks served by water suppliers. The 1997 parcel data and the Census data determine the housing density variable. Each block group has unique values for median income, household size, and housing density and is assigned to one service area as shown in figure 2. Block-group averages are presented for parcel size (figure 3) and median household income (figure 4).

Using actual quantity data, equation 1 is used to estimate the intercept, α, for summer and winter consumption in each service area. Each service area has unique summer and winter values for marginal price, fixed costs, and the intercept. Using the elasticities in table 1 and the intercepts in table 3, the average daily consumption is calculated. Summary data are presented describing estimated water consumption by parcel size (table 2) and by supplier (table 3). These estimated consumption relationships provide the basis for the analysis in the next section.

IV. Results

The analysis was performed in ARCView, using a GIS constructed by the authors at the University of Delaware. Equation 1 establishes baseline water consumption, presented spatially, by block, including quantity (figure 5) and price (figure 6). The results suggest that residential water use varies directly with residential parcel size. Parcel size tends to vary directly with median block-group income. Block-level data is used to infer the characteristics of residential parcels in each block in order to conduct countywide comparisons of estimated “household” characteristics. Households with median incomes below $30,000 per year account for 6.8 percent of the population, but these households are responsible for only 3 percent of the summer water demand. In contrast, households with mean incomes greater than $100,000 per year represent 4.8 percent of the population and are responsible for 14 percent of the summer demand. The newer growth areas in the northern and southern areas tend to have parcel sizes of a quarter acre and greater and have above average incomes. One expects that parcel size and income vary directly with more expensive landscaping and swimming pools that require more water during the summer months. The 15 percent of households with minimum half-acre parcels consume 30 percent of the summer water. A comparison between summer and winter consumption (not shown graphically) found that 20 percent of households consume between 60 percent and 137 percent more during the summer. These high-consumption block groups are located in the newer growth areas. The block groups with little variation in their seasonal usage tend to be located in the established urban areas located near Interstate 95, which runs from the southwest to the northeast in New Castle County.

Analysis—The Scenarios

The results of the pricing scenario are represented by figures 7 and 8. The results suggest that the burdens of quantity reduction and cost increases will tend to fall in areas with larger parcel sizes and higher incomes. Established areas will reduce consumption slightly and will see an increase in their quarterly bill of 100 to 200 percent for a three-month deficit. The 30 percent of households that will reduce daily consumption by more than 25 percent of normal summer consumption when the marginal price increases by 591 percent are responsible for 54 percent of the normal consumption. Also, the 30 percent of the households faced with more than a 200 percent increase in their quarterly bill consume 44 percent more water in the summer than winter. The new-growth areas with larger parcels and higher incomes can expect at least a 200-percent increase in their bills during times of deficit, even after reducing consumption between 26 and 40 percent.

The water-rationing scenario in figure 9 and 10 presents a sharing of water-deficit burden among households proportionate to non-deficit consumption. Figure 10 is presented in terms of "gallons reduced" rather than "percent reduction" because each block was responsible for a 25 percent reduction. Since price does not change, the burden occurs as unfulfilled demand. Shortages are mitigated during deficits by a lowering of a consumer's bill, though, presumably, when the deficit ends, the suppliers will seek to raise their rates for all users to recoup their losses. There will be 16.6 percent of households with unfulfilled demand in excess of 100 gallons per day. These households consume 37.5 percent of the water in non-deficit periods and have an average income of $84,721. In contrast, 47 percent of households will face less than 50 gallons per day of unfulfilled demand. These households consume 24.7 percent of the water in non-deficit periods and average $42.243 in income. Consumption responses to rationing also vary with housing density. The larger consumptive group (over 100 gallons of unfulfilled demand) averages 1.4 households per acre, while the smaller consumptive group (less than 50 gallons of unfulfilled demand) averages 6.3 households per acre. This lower consumer group uses 9.5 percent more water in the summer than winter while the larger consumer group uses 54.7 percent more water in the summer.

The mandatory restriction scenario in figures 11 and 12 captures a policy that restricts outdoor use of water. The mandatory restriction achieved a 25 percent reduction by targeting the 75 percent of households on greater than 0.10 acre lots. Under this policy, small-lot residents are unaffected by drought; their rates do not change and neither should their consumption. These residents unaffected by the restriction are concentrated in the urban areas, particularly the City of Wilmington. Residents on larger lots bear the entire burden of the deficit in the form of unfulfilled demand, although their water bills will be reduced with their attenuated consumption. All consumers will likely face higher rates in the quarter following a drought in order to meet the suppliers' cost-recovery needs. Under this policy, 30.4 percent of households consume 52.6 percent of water during deficits and have per capita consumption greater than 100 gallons per day. These households have median income of $69,598. In contrast, 40.3 percent of households will have per capita consumption below 70 gallons per day and will consume 21.0 percent of the summer water. These lower-use households have a median income of $43,361.

V. Implications

Water conservation policies are an important complement to supply-side solutions in deficit planning. The three conservation scenarios applied to data from New Castle County all produced the same effect—a 25-percent reduction in consumption. The distributional effects, however, were quite distinct. Rationing forced households with lower consumption to forgo essential uses, while households with high consumption were able to conserve at the nonessential margin. The mandatory restriction was more equitable in the treatment of low consumptive households, but provided a rather blunt incentive for efficient consumption. Both rationing and mandatory restrictions may also result in cost recovery in the next nondeficit quarter, which will raise rates for all consumers regardless of their behavior during the drought. Only pricing water above a threshold to reflect its scarcity allows consumers to decide efficiently how to conserve by eliminating the less-valued uses. Pricing also ensures that all costs resulting from the deficit are incurred during the deficit and in proportion to consumption during the deficit.

The application to New Castles County found that those households with the largest potential to conserve live in the newer growth areas of the county. These households have higher summer demand as well as relatively high incomes and large parcels. The need to irrigate landscape plants can help explain the disparity between summer and winter consumption. The lower consumptive households are located in established neighborhoods along the Interstate 95 corridor. These residents are characterized by lower than average incomes on smaller properties.

Overall, the application demonstrated that a 591 percent increase in the marginal price of water in times of deficit would achieve the same aggregate conservation goals as rationing and mandatory restrictions. Of course, implementation of water-scarcity pricing is problematic. Most consumers are unaware of the relationship between their water-consumption activities and the marginal contribution to their quarterly water bill. Even if the suppliers or the government could effectively forecast the appropriate price increase and signal consumers, it still would be difficult for consumers to adjust their water-consumption behavior efficiently. Other policies also have implementation problems, though perhaps less challenging than those of water-scarcity pricing. Mandatory restrictions require enforcement, the costs of which are somewhat self-financing through the use of fines. Rationing may be the most direct way to address deficits. Yet the effectiveness of rationing is tempered as consumers overconsume when the "water is on" to hedge against times when the "water is off".

It seems that a minimum requirement for equity is that essential water remain affordable during periods of deficit. Nonessential water should be priced, at the margin, to reflect its relative scarcity. A higher marginal price would encourage suppliers to seek temporary purchases of water from regional suppliers or for the construction of additional supply sources. Pricing water above threshold consumption puts the conservation burden on the households that contribute the most to peak summer demands as well as immediately addressing the cost recovery needs of suppliers. A political issue remains for the disposition of the additional revenue from pricing—no such issue is associated with rationing and mandatory restrictions. As such, water-scarcity pricing offers the flexibility of using additional revenue to lower rates during nondeficit periods.

Although the purpose of this paper was to analyze demand-side policies for conservation, it is also important to consider the implications of the results on planning for large-scale, supply-side projects for deficit management. Returning to the application, there were important ramifications of the 1999 drought in Newark, Delaware. Property owners in Newark overwhelmingly approved referenda in 2000 and 2001 for construction of a 300 million gallon reservoir, including an approximately $8 million property-tax increase to purchase of the land and $16 million in bonds for construction (Besso 2001). The construction costs will be recouped through a permanent 84 percent increase in water rates on the margin—from $1.82 to $3.34 per 1000 gallons. It is instructive to compare these costs to that of water-scarcity pricing. When a 591 percent increase in marginal price above the 48 gallon per day threshold is applied to the City of Newark in the pricing scenario, residential demand is reduced by 25 percent. The additional cost per month of drought—the same length as the mandatory restrictions in 1999—is approximately $567,000. This additional revenue could be used for purchasing water or for reducing nondeficit rates. Though the analysis did not consider the costs to businesses for reducing their consumption and though a drought may require more or less than a 25 percent reduction, the tremendous disparities in the impact of water-scarcity pricing versus supply-side solutions warrant further consideration of using a price incentive to achieve conservation goals.

Table 1

Equation 1 Elasticities of Residential Water Use in New Castle County

Explanatory Variable	Single-Family Summer	Single-Family Winter
Income	+0.40	+0.40
Persons per Household	+0.40	+0.45
Housing Density	-0.65	-0.30
Marginal Price	-0.25	-0.04
Fixed Charge	-0.0005	-0.0005
Maximum Daily Temperature	+1.50	+0.45
Total Rainfall	-0.25	-0.02

Table 2

Block Average Consumption by Parcel Size

Parcel Size (acres)	Blocks		Estimated Household Data				Parcel Groupings	
	Number	%	Number	%	Median Income ($)	Summer Water Use (gallons/day)	Summer Water Use (gallons/day)	%
< 0.2	132	37.9	61,288	38.4	39,456	140	8,580,465	20.9
0.2 to 0.3	81	23.3	31,631	19.8	57,217	225	7,109,648	17.3
0.3 to 0.4	42	12.1	20,600	12.9	66,501	296	6,093,688	14.9
0.4 to 0.5	38	10.9	22,334	14.0	68,638	314	7,017,922	17.1
0.5 to 0.6	16	4.6	4,740	3.0	72,337	435	2,063,773	5.0
0.6 to 0.7	12	3.4	5,637	3.5	81,552	433	2,442,651	6.0
0.7 to 0.8	4	1.1	3,509	2.2	86,960	559	1,962,079	4.8
> 0.8	23	6.6	9,695	6.1	72,471	590	5,720,705	14.0
Total	348		159,434		55,183	257	40,990,931	

Table 3

Block Average Consumption by Supplier

	Blocks		Households			Supplier Level				
Supplier	Number	%	Number	%	Number Per Acre	Intercept (Winter)	Intercept (Summer)	Summer Water Use (gallons/day)	%	Ratio: Summer / Winter
Artesian	121	34.8	60,379	37.9	2.3	631.0822	19.43747	17,351,837	42.3	1.32
Wilmington	133	38.2	45,972	28.8	5.5	1094.73	36.2151	13,372,278	32.6	1.185
United	68	19.5	38,753	24.3	3.1	596.1727	14.90107	7,306,467	17.8	1.02
Newark	18	5.2	11,445	7.2	2.8	609.006	14.92203	2,435,694	5.9	1.06
New Castle	6	1.7	2,153	1.4	2.9	615.7689	15.01914	395,631	1.0	1.015
Del. City	2	0.6	732	0.5	3.4	714.3107	15.41507	129,024	0.3	1.1
Total	348		159,434		3.1			40,990,931		

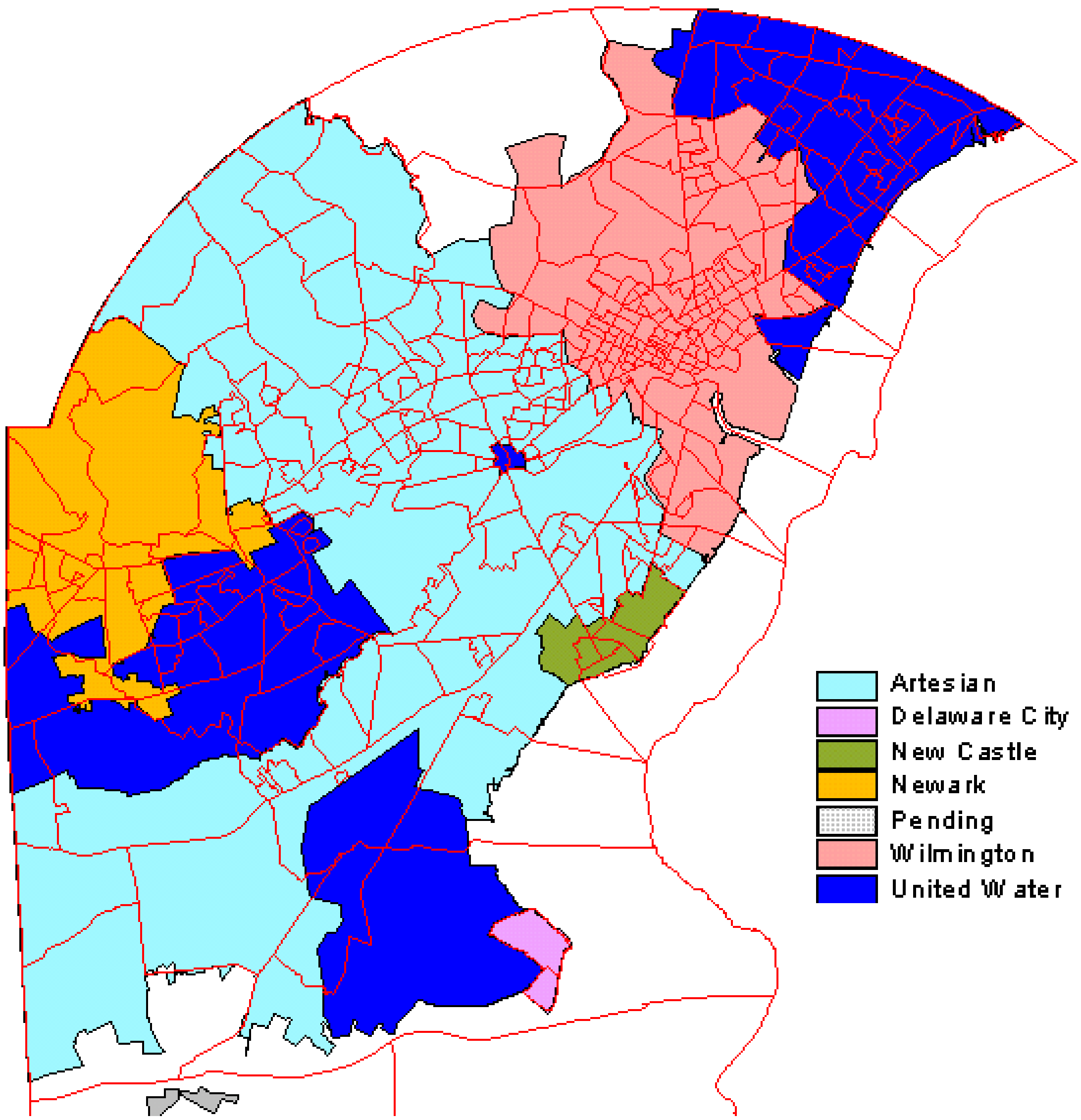

Figure 1: Water Service Areas in New Castle County, Delaware

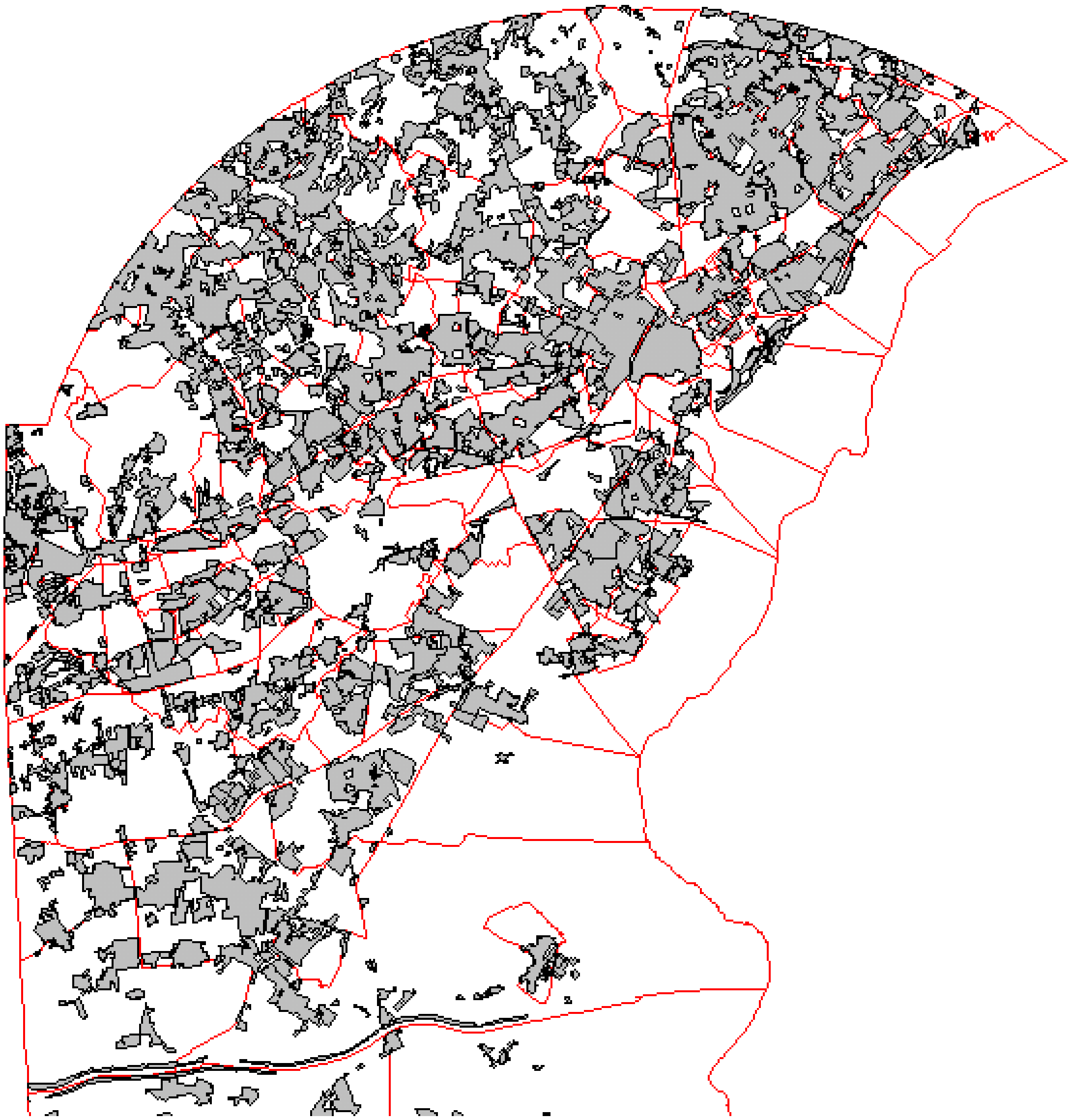

Figure 2: Residential Areas in New Castle County, Delaware

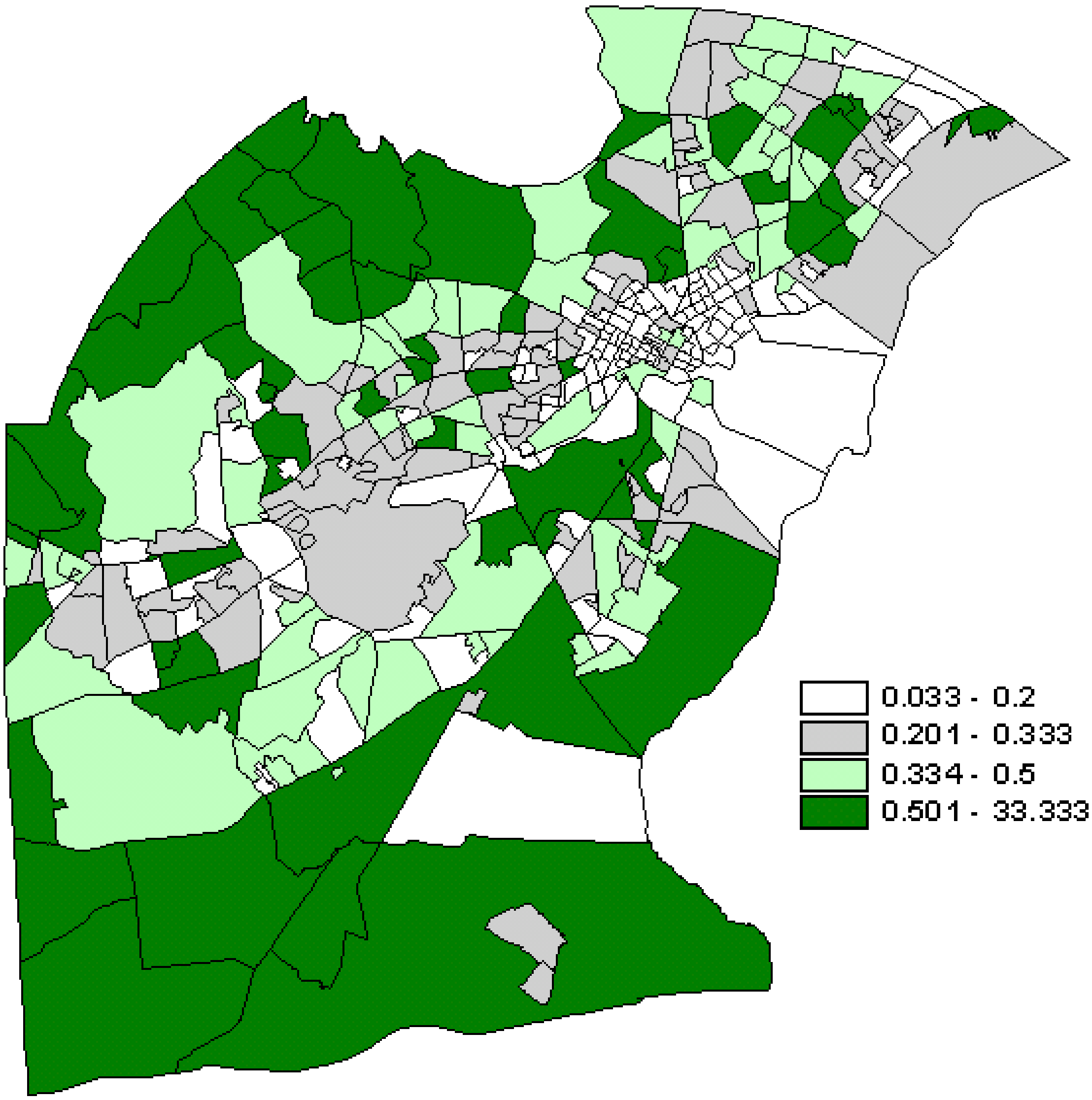

Figure 3: Average Parcel Size by Block (acres)

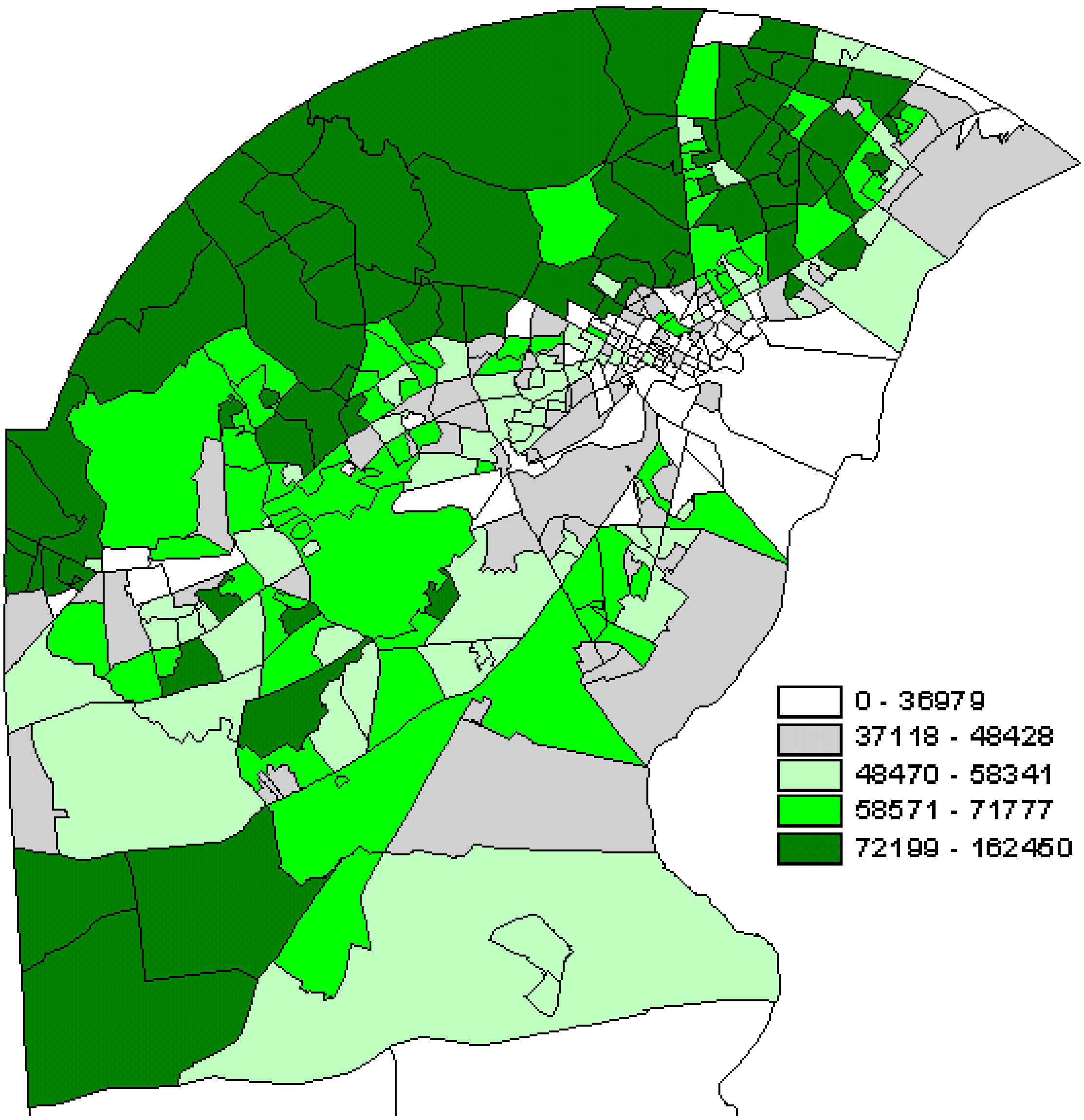

Figure 4: Median Household Income by Block (dollars, 1998)

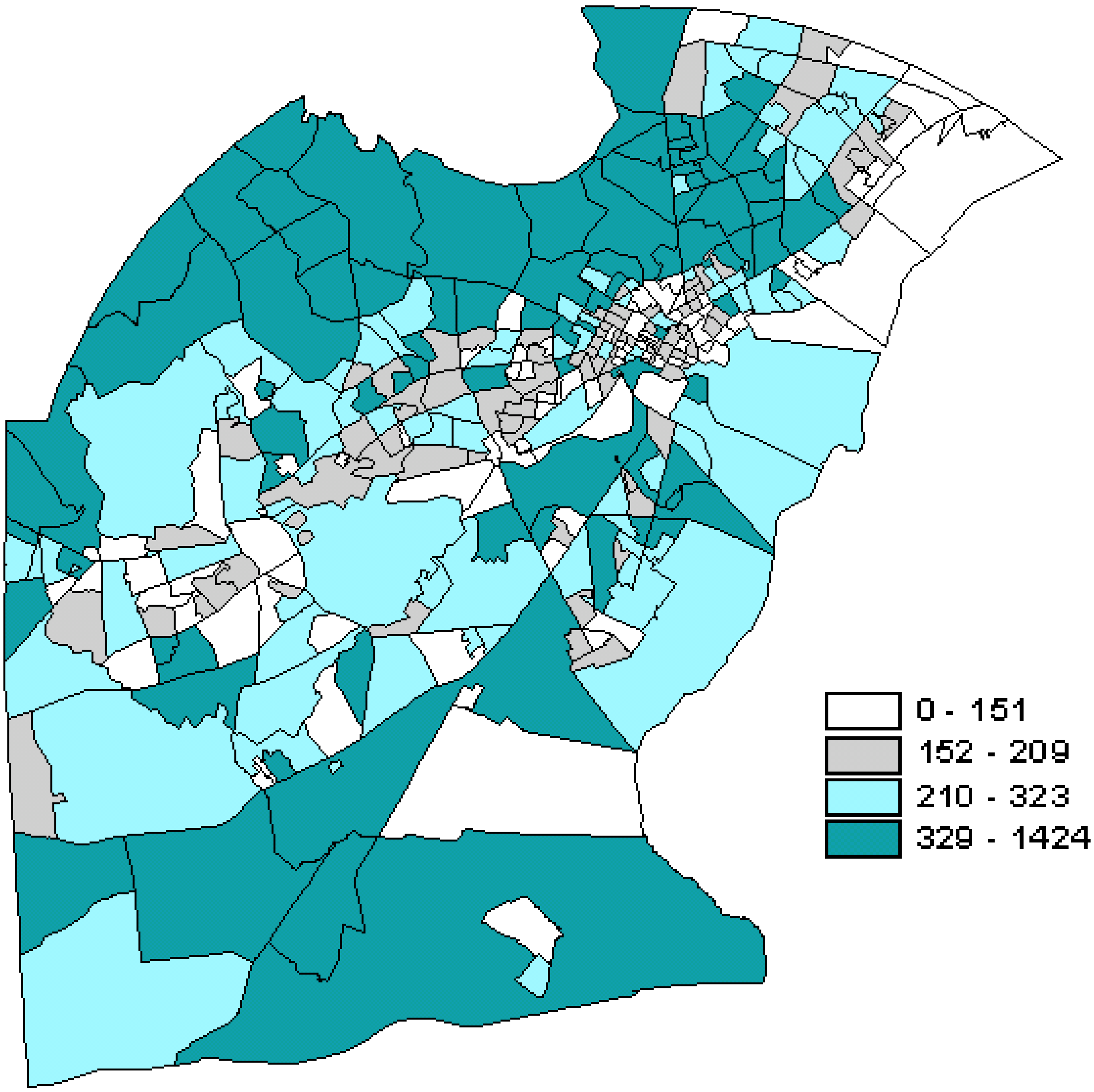

Figure 5: Baseline Estimated Daily Summer Demand by Block (gallons per day)

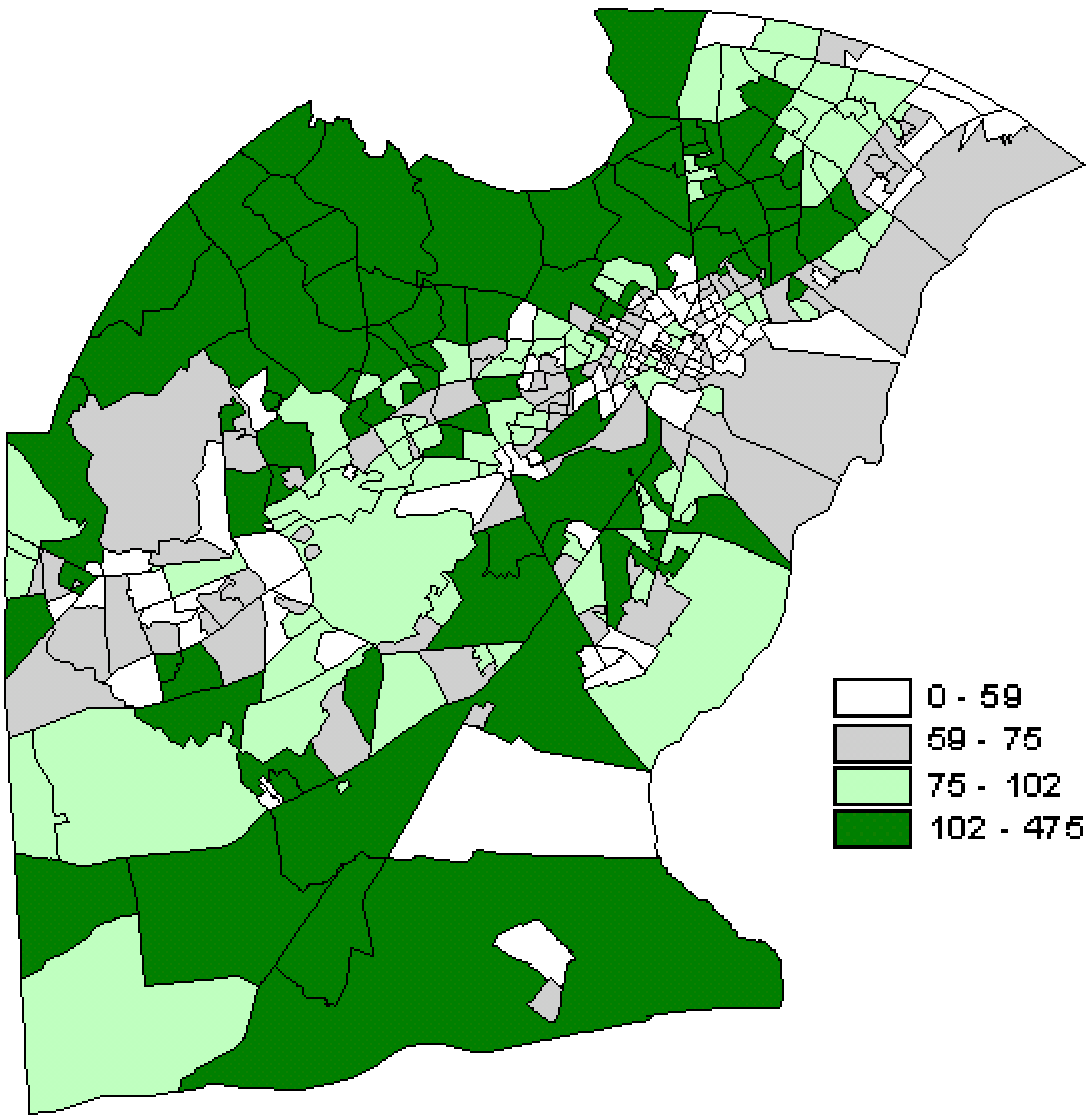

Figure 6: Baseline Estimated Summer Quarterly Bill by Block (dollars)

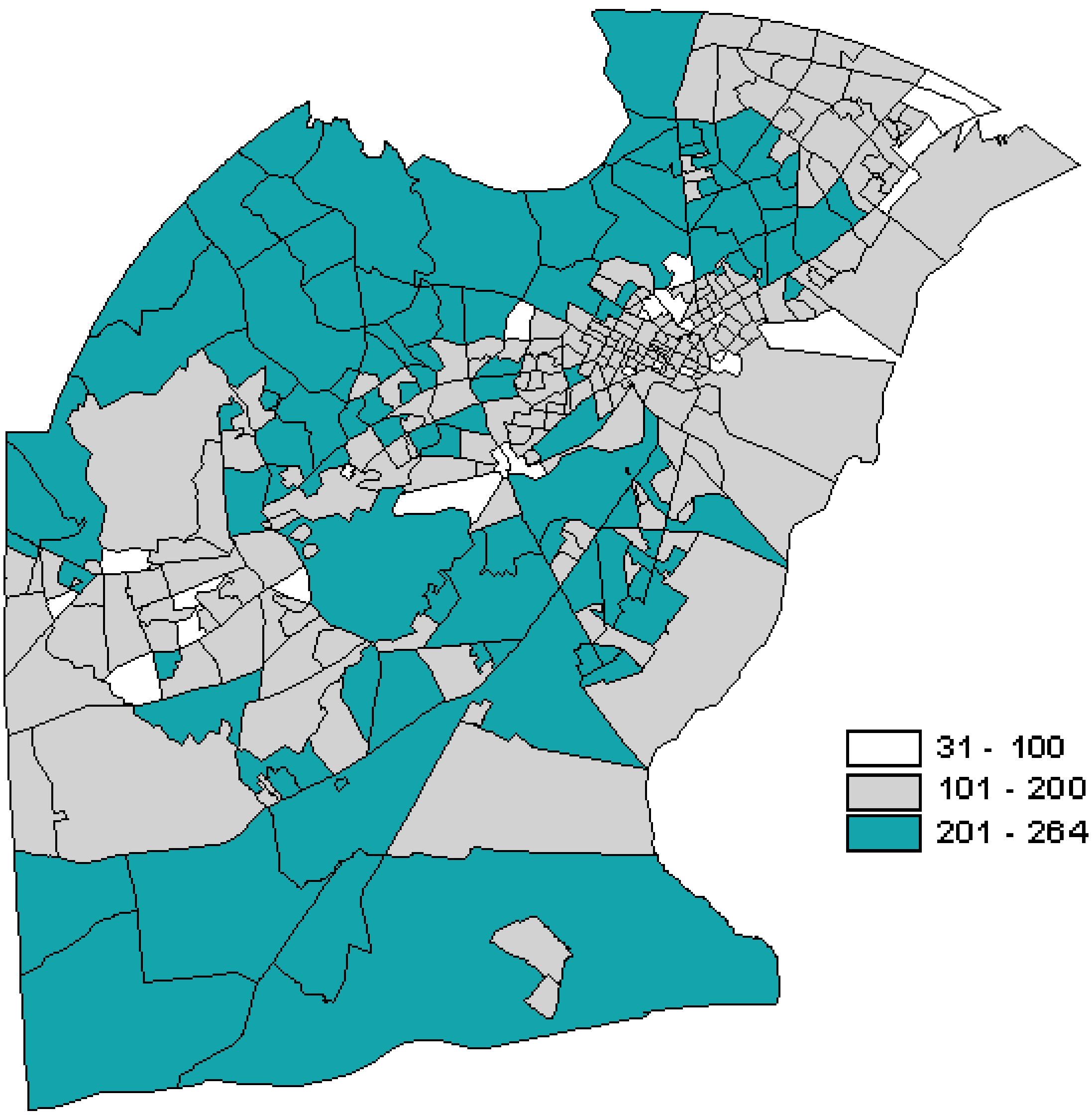

Figure 7: Scenario 1—Increase in Estimated Quarterly Bill by Block (percent)

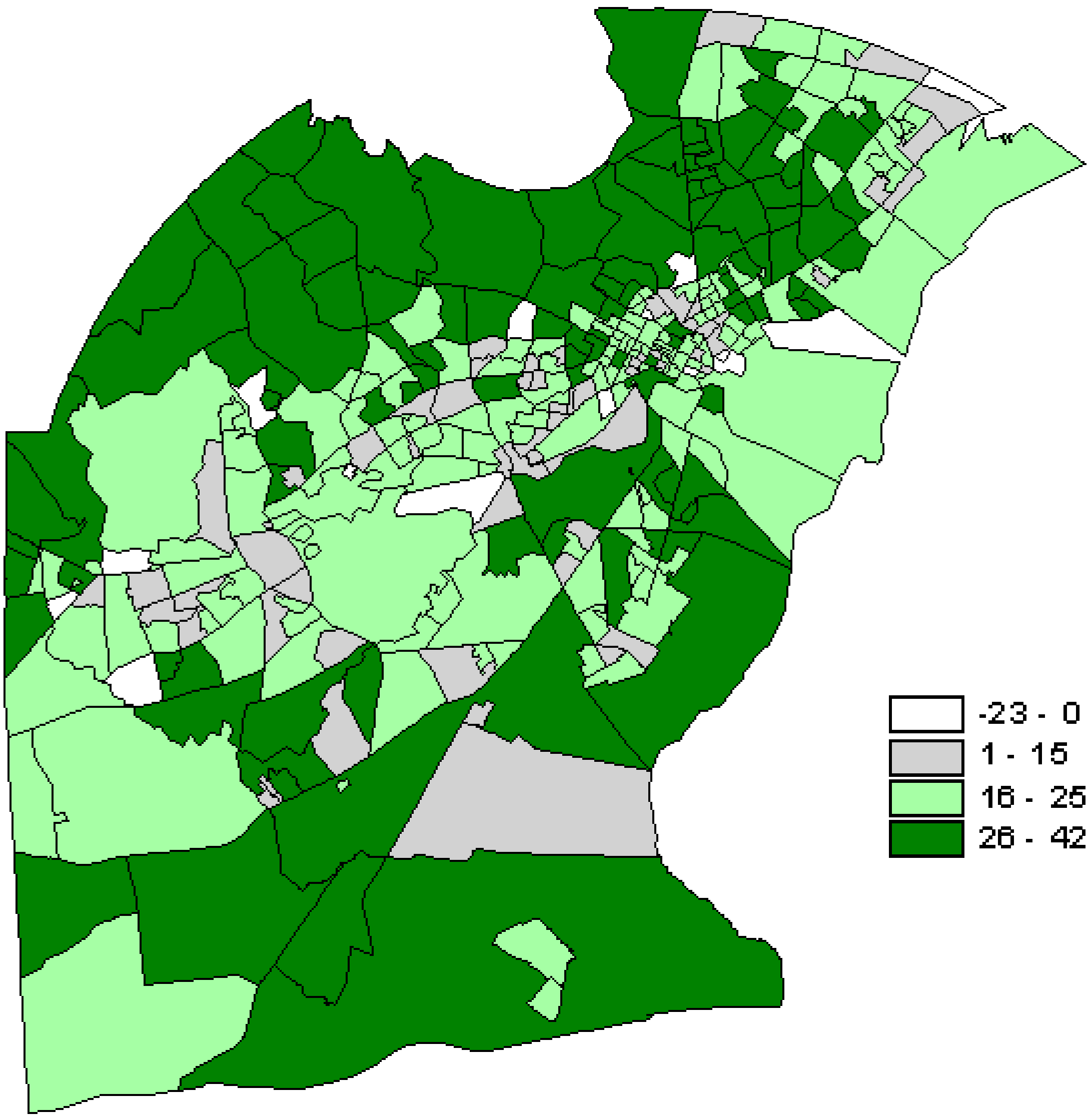

Figure 8: Scenario 1—Decrease in Quantity Demand by Block (percent)

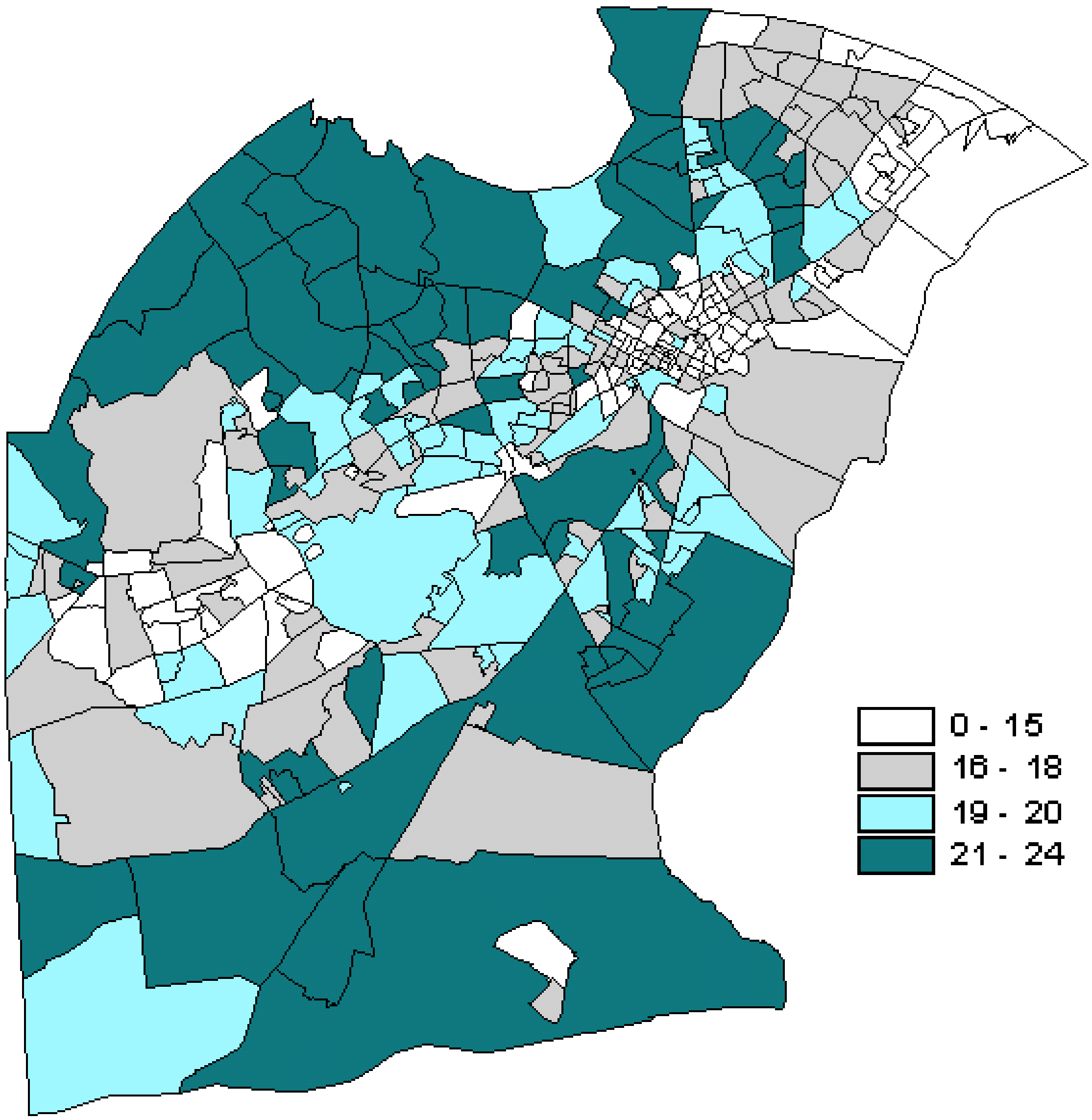

Figure 9: Scenario 2—Decrease in Estimated Quarterly Bill by Block (percent)

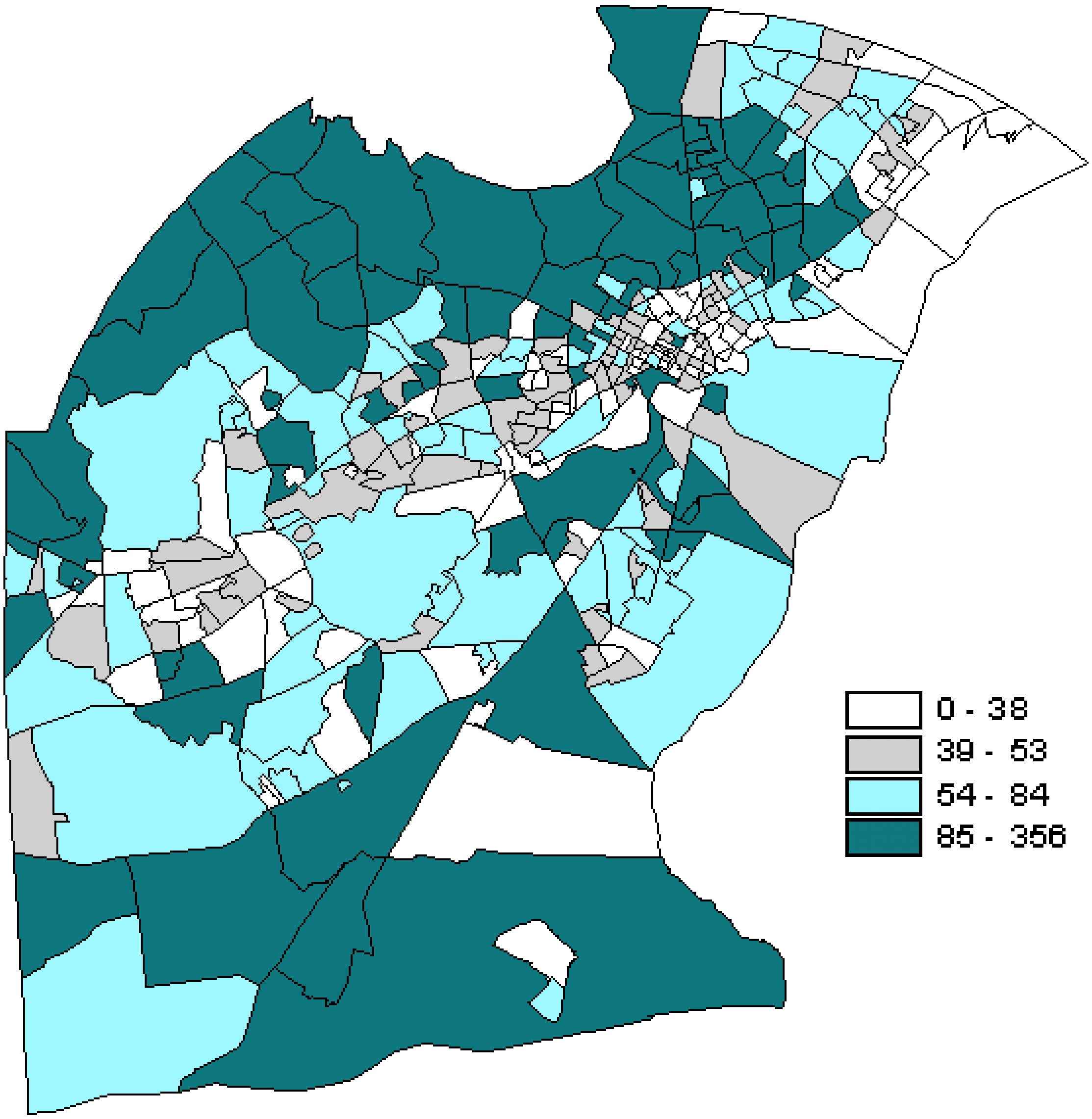

Figure 10: Scenario 2—Decrease in Quantity Demanded by Block (gallons per day)

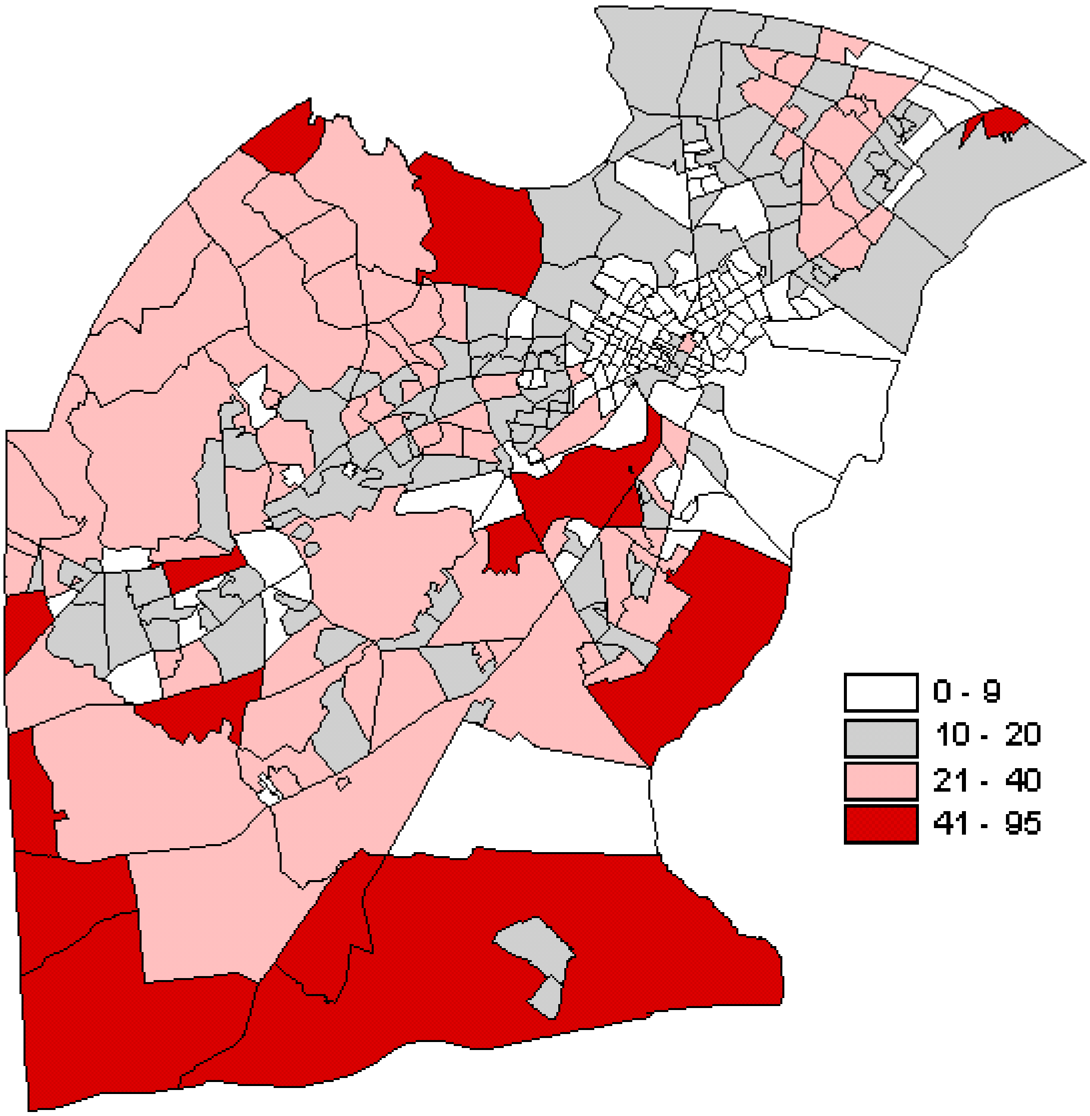

Figure 11: Scenario 3—Decrease in Estimated Quarterly Bill by Block (percent)

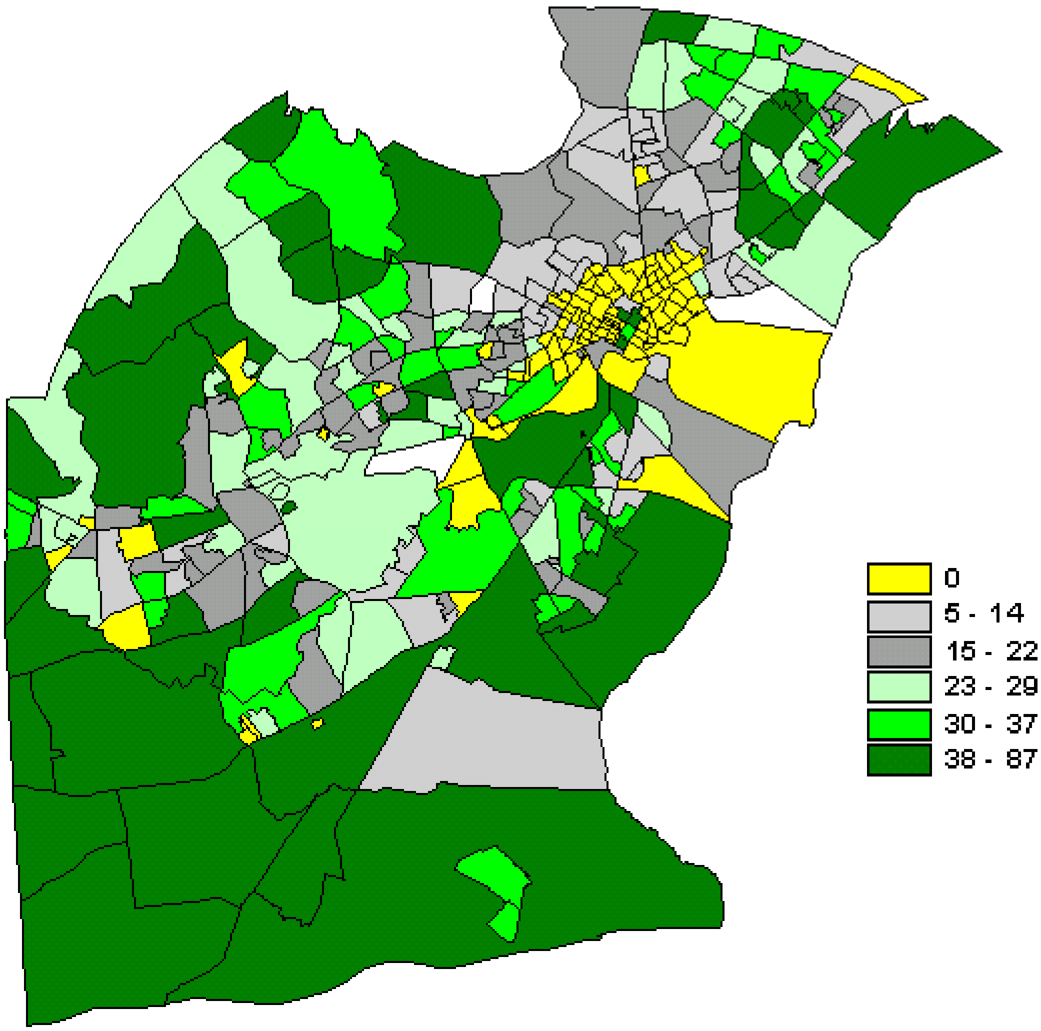

Figure 12: Scenario 3—Decrease in Quantity Demanded by Block (percent)

Works Cited

Aitken, Campbell K., Thomas A. McMahon, Alexander J. Wearing, and Brian L. Finlayson. 1994. Residential water use: Predicting and reducing consumption. *Journal of Applied Social Psychology* 24(2):136-58.

Barrish, Cris. 1999. Newark must set a ration plan. *The News Journal* August 14.

Besso, Michele. 2001. Newark voters approve reservoir. *The News Journal* April 11.

Chesnutt, Thomas W. and Janice A. Beecher. 1998. Conservation rates in the real world. *American Water Works Association* 90(2):60-70.

Cohen, Harvey D. and Kenneth L. Golub. 1996. Valuation of potable water east of the Mississippi River. *Appraisal Journal* 64(3):279-88.

Cuthbert, Richard. 1989. Effectiveness of conservation-oriented water rates in Tucson. *American Water Works Association* 81(3):65-73 .

Delaware Water Resources Agency. 2000. *Economic Synthesis of Water Rates in Delaware and Surrounding River Basins*. Newark, Delaware: Institute of Public Administration, University of Delaware.

Delaware Water Resources Agency, Delaware Geological Task Force, and Delaware Department of Natural Resources. 1999. *The Final Report: Governor's Water Supply Task Force*.

Dunphy, Harry. 2000. Population group sees progress, less pressure on drinking water, cropland. *Associated Press*, August 24.

Espy, M., J. Espy and W. D. Shaw. 1997. Price elasticity of residential demand for water: A meta-analysis. *Water Resource Research* 33(6):1369-74.

Hurd, Merna. 1998. *Water Demand Trends & Future Water Needs: New Castle County, Delaware*. Dover: Delaware Department of Natural Resources and Environmental Control.

Jordan, Jeffrey L. and Rick Albani. 1999. Using conservation rate structures. *American Water Works Association* 91(8):66-73.

Lehman, Stan. 2000. Sao Paolo braces for water rationing. *Associated Press*, May 31.

Loucks, Daniel P. 1999. *Sustainable criteria for Water Resource Systems*. Cambridge: Cambridge University Press.

Mayor, Federico. 1997. Water and civilization. *UNESCO Courier* 57(3):36-8.

Montgomery, Jeff. 2000. Del. Among worst in air quality: Some toxins linked to cancer, EPA says. *The News Journal* August 27:A1-A12.

Nelson, John Olaf. 1992. Water audit encourages residents to reduce consumption. *American Water Works Association* 84(4):59-64.

Optiz, Eva M., John F. Langowski, Benedykt Dziegielewski, Nancy A. Hanna-Somers, J. Scott Willett, and Richard J. Hauer. 1998. Forecasting Urban Water Use: Models and Application, *in* Duane D. Baumann, John J. Boland, and W. Michael Hanemann, *Urban Water Demand Management and Planning.* New York: McGraw-Hill.

Pint, Ellen M. 1999. Household responses to increased water rates during the California drought. *Land Economics* 75(2):246-66.

Renwick, Mary E. and Sandra O. Archibald. 1998. Demand side management policies for residential water use: who bears the conservation burden? *Land Economics* 74(3):343-60.

Rosenberg, Mathew J. 2000. Jamaica to limit water supply. *Associated Press*, April 6.

Tippett, Sherry J. and Craig O'Hare. 1999. Using price to limit water use: A case study of the City of Santa Fe. *Natural Resources Journal* 39(1):169-73.

U.S. Department of Commerce, Bureau of the Census. 1990. *1990 Census of Population*. Washington, D.C.: Government Printing Office.

Wood Warren W. 1999. Water use and consumption: What are the realities? *Groundwater* 37(3):321-22.

WorldClimate. 2001. Data on New Castle County, Delaware, accessed 21 January 2001, http://www.worldclimate.com/cgi-bin/data.pl?ref=N39W075+2200+076410C and http://www.worldclimate.com/cgi-bin/data.pl?ref=N39W075+2200+1076410G2

The Department of Food and Resource Economics
College of Agriculture and Natural Resources
University of Delaware

The Department of Food and Resource Economics carries on an extensive and coordinated program of teaching, organized research, and public service in a wide variety of the following professional subject matter areas:

Subject Matter Areas

Agricultural Finance
Agricultural Policy and Public Programs
Environmental and Resource Economics
Food and Agribusiness Management
Food and Fiber Marketing
International Agricultural Trade
Natural Resource Management
Operations Research and Decision Analysis
Price and Demand Analysis
Rural and Community Development
Statistical Analysis and Research Methods

The department's research in these areas is part of the organized research program of the Delaware Agricultural Experiment Station, College of Agriculture and Natural Resources. Much of the research is in cooperation with industry partners, other state research stations, the USDA, and other State and Federal agencies. The combination of teaching, research, and service provides an efficient, effective, and productive use of resources invested in higher education and service to the public. Emphasis in research is on solving practical problems important to various segments of the economy.

The department's coordinated teaching, research, and service program provides professional training careers in a wide variety of occupations in the food and agribusiness industry, financial institutions, and government service. Departmental course work is supplemented by courses in other disciplines, particularly in the College of Agriculture and Natural Resources and the College of Business and Economics. Academic programs lead to degrees at two levels: Bachelor of Science and Masters of Science. Course work in all curricula provides knowledge of tools and techniques useful for decision making. Emphasis in the undergraduate program centers on developing the student's managerial ability through three different areas, Food and Agricultural Business Management, Natural Resource Management, and Agricultural Economics. The graduate program builds on the undergraduate background, strengthening basic knowledge and adding more sophisticated analytical skills and business capabilities. The department also cooperates in the offering of an MS and Ph.D. degrees in the inter disciplinary Operations Research Program. In addition, a Ph.D. degree is offered in cooperation with the Department of Economics.

For further information write to: Dr. Thomas W. Ilvento, Chair
Department of Food and Resource Economics
University of Delaware
Newark, DE 19717-1303

FREC Research Reports

are published as a

service to Delaware's

Food and Agribusiness

Community by the

Department of

Food and Resource

Economics, College

of Agriculture and

Natural Resources

of the University of

Delaware.