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An Analysis of Residential Water Demand and Water Rates in Minnesota

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FOREWORD

This bulletin is published in furtherance of the purposes of the Federal Water Resources Research Act of 1964. The purpose of the Act is to stimulate, sponsor, provide for, and supplement present programs for the conduct of research, investigations, experiments, and the training of scientists in the field of water and resources which affect water. The Act is promoting a more adequate National program of water resources research by furnishing financial assistance to non-Federal research.

The Act provides for establishment of Water Resources Research Centers at Universities throughout the Nation. On September 1, 1964, a Water Resources Research Center was established in the Graduate School as an Interdisciplinary component of the University of Minnesota. The Center has the responsibility for unifying and stimulating University water resources research through the administration of funds covered in the Act and made available by other sources; coordinating University research with water resources programs of local, State and Federal agencies and private organizations throughout the State; and assisting in training additional scientists for work in the field of water resources through research.

This Bulletin is number 96 in a series of publications designed to present information bearing on water resources research in Minnesota and the results of some of the research sponsored by the Center. This Bulletin examines price elasticity of demand for residential water in Minnesota and implications for public policy.

This Bulletin is related to the following research project:

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Publication Abstract:

Price elasticity of demand for residential water in Minnesota is examined, along with policy implications. Common rate forms for pricing municipal water are described and analyzed. Recommendations for improving rate structures in Minnesota are made in light of theoretical and empirical considerations.

INTRODUCTION

Of the inputs essential to man's existence, clean water has to be ranked at the top. Its uses are myriad. Water for drinking and growing food is key, while water for washing comes close behind. As cities developed, water came to be used to carry away wastes. More recently, it is used to grow greenery in city environments to make them more aesthetically pleasing. And of course, water is also essential in agriculture and countless industrial processes.

Yet water has historically been treated in the United States as nearly a free good. Settlers in the humid East found pure water in such quantities that it could be used for any practical purpose. Americans maintained their habits of abundant consumption as they moved West. Instead of curbing consumption, Yankee ingenuity was used to augment water supply.

As public water systems developed, this philosophy was maintained. Because water is such an essential item, it was priced at very low levels. At these cheap prices new uses for water developed. Coupled with growing populations, demand skyrocketed. The fact that demand constantly outstripped water supply hints that the price was artificially low. Bond issues were usually required to finance expansions of water systems.

One result has been that America's vast water resources have been extensively exploited. Most rivers were used as free dumping grounds for wastes until they could no longer be used for municipal purposes. Groundwater resources were then tapped and in some cases used at a rate much faster than recharge. In the West entire rivers are pumped dry in the summer, and interbasin transfers pipe water across long distances. Rationing has been necessary in several Western cities. Water is not a free good in any sense any more. Indeed, it is becoming increasingly scarce, and droughts serve to emphasize this point.

The dry weather of the last two or three years has brought much attention to the water resources problems of this state. It is becoming apparent just how little is known about the surface and groundwater resources of Minnesota and the effect of water use practices upon them. Unfortunately, a season of generous rains can wash away these problems in the eyes of many people. Just as a heavy rain can erode topsoil on a farmer's field, so it erodes the interest in more permanent solutions to water allocation decisions. This study intends to examine in detail one aspect of water use, residential consumption, in the hope that more information may lead to more efficient use of this scarce good.

Scarcity is promoted through the use of the requirements or water needs approach to demand forecasting. In this technique, water needs are projected or extrapolated by measuring the growth in population and in water use per capita. As an example, the 1970 Minnesota State Planning Agency's assessment of Minnesota's water and related land resources projects that per capita municipal water use will increase to 92 gallons per day (gpd) in 1980, 106 gpd in 2000, and 113 gpd in the year 2020. Accordingly, the Twin Cities, Worthington, and the Iron Range area would need additional water supplies by 1980. New Ulm will have to augment its supply by 2000 and Marshall in 2020.

Notice that there was no mention of price in the projection process. This method makes no use of the flexibility of demand through price changes. Water needs, not water demands which allow for price changes, are being measured. Indeed, demand for water is assumed to be perfectly inelastic, a vertical demand function. In other words, the price of water does not affect the quantity of water used; the price elasticity of demand is zero.

Doubts about the validity of this assumption were the impetus for the first part of this study. If the price elasticity is found to be significantly different from zero, then the assumptions behind the requirements approach to water demand forecasting are refuted. The role of price and the market system in determining equilibrium in resource use is bolstered.

Price elasticity of demand is also very important because it shows how much water will be conserved by a price increase. It may be cheaper to raise the price of water than to expand water supply systems for low-value uses such as lawn sprinkling. The first phase of this research will thus look at residential water demand and the effect of price and other factors on this demand.

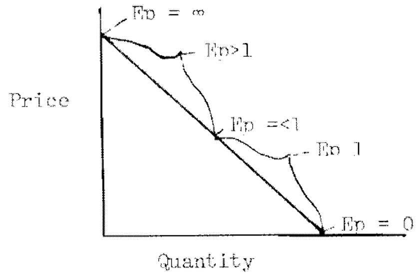
Since price elasticity depends on the marginal price, or the price of the last unit of a good purchased, this measure of water prices is very significant. Water rate structures have a controlling impact on marginal price and therefore price elasticity of demand. The second part of this study analyzes rate structures in Minnesota and their effect on water use. Some possible changes in rate structures are discussed, and finally, some recommendations relating to Minnesota water policy are made.

PROCEDURE

To determine the price elasticity of demand for residential water, a demand function must be determined.[1/] This will be accomplished by finding sets of consumption and water price figures of different towns. The statistical method of least squares regression will then find the most accurate relationship between water consumption and price.

Note that price changes within a town are not being used, but rather price differences between towns. This is a weakness of this cross-sectional technique, but if the water demand functions for each town are similar, the results should be a reasonable approximation of reality.

[1/] A few economic concepts need to be clarified. Demand, of course, shows the relationship between price and the quantity purchased of a product. The price elasticity of demand (Ep) is the relative responsiveness of quantity demanded changes in price. It can be expressed as a point elasticity which measures the elasticity at one point on the demand curve. This would be $\frac{\partial QP}{\partial PQ}$ or the partial derivative of quantity with respect to price times price over quantity. More commonly, elasticity is mathematically described as $\frac{\Delta Q}{Q} \div \frac{\Delta P}{P}$ or $\Delta QP/\Delta PQ$. A similar concept, the income elasticity of demand, explains the response in quantity demanded to changes in relative income levels.

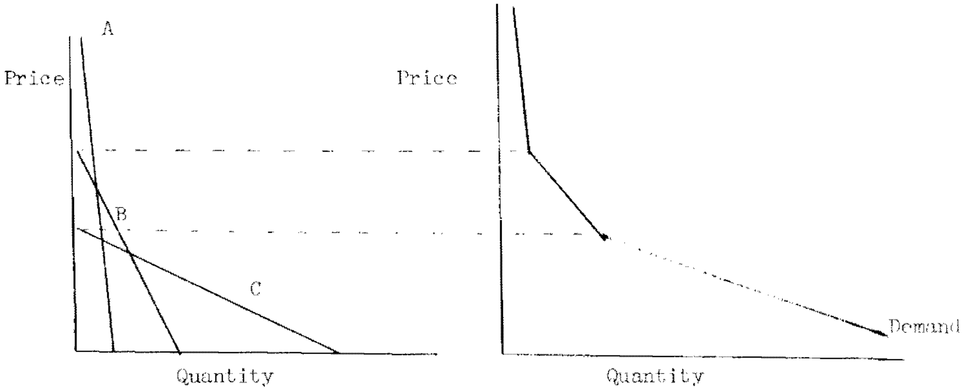


The price elasticity of demand changes from zero to infinity as one moves along a linear demand curve. The graph above shows this. The segment above the point of unitary elasticity is the elastic portion of the demand curve, and that below is the inelastic area. Total revenue is largest where the price elasticity equals one, and this is something for the water utilities to consider. Price increases will continue to increase revenue as long as Ep is less than unity.

The Demand for Water

As implied in the introduction, different uses for water have varying priorities. This is because the benefits to society from using an increment of water for a particular use vary according to the use and the quantity of water already in that use. So the demand for water could be conceived as the summation of several different demand curves for the different uses. This idea is illustrated by Figure 1 where A, B, and C represent the demands for water for three different purposes. Non-zero elasticity is assumed. When the individual demands are added, the total demand for water is obtained. A, B, and C could be different demand sectors such as Residential, Industrial, and Agricultural. They could also represent different uses within a sector. The demands for drinking and cooking, washing, and sprinkling must be added to obtain residential water demand. The demand curve for residential water is thus conceived as having one or more kinks in it as different uses become economically feasible, and water is demanded for them. If there are enough distinct uses of varying utility, the demand function may approach the shape of a smooth curve.

Figure 1. Demand Curve for Residential Water.



If the demand function is linear one would expect the price elasticity of demand to increase as price increases. If there are kinks in the demand function, as is surmised for residential water demand, then this trend is tempered. As price increases, elasticity increases until a kink is reached. Due to the increased slope of the demand curve, elasticity falls at that point whereupon it again begins to slowly increase. The expected behavior of the price elasticity depends also upon the shape of the demand curve.

The Survey

Since this study is focusing on residential water use, it is necessary to know what proportion of a city's water is used for residential purposes, and what is used for commerical, institutional and industrial uses. When the amount of residential use is divided by the population served by the water system, per capita water consumption is found. A demand function can then be calculated by seeing how price and other explanatory variables affect per capita consumption.

In order to obtain the data on water sales, rate structures for both water and sewer, and a breakdown into demand sectors, a survey was necessary. In early August of 1976, a mail survey was sent to the city clerk of every municipality having a public water system listed in the Minnesota Department of Health records. The survey was endorsed by the Department of Health as well as the University of Minnesota's Department of Agricultural and Applied Economics. A sample of the survey form is found in the appendix.

In the water demand studies by Wong (45) and Fourt (11), it was noted that the r^2, or proportion of variation explained, decreased with the size of the cities used in the regression equations. Least squares regression also tends to be more accurate over a limited range. Therefore, it was decided to constrain the cities to be included in this demand study to a certain population range. Twenty-five hundred persons was a logical lower boundary, as U.S. Census Bureau detailed data for municipalities begins at this point. Twenty-five thousand persons was chosen as the upper bound. All Minnesota cities with a public water system with a 1970 population within this range were included within the original sample. The population of some cities may since have fallen below twenty-five hundred or grown beyond twenty-five thousand.

Of the six hundred fifty surveys sent to Minnesota municipalities, only one hundred twenty-five were applicable to this study. Three hundred thirty-nine of or fifty-two percent of all surveys were returned. However, with the help of followup telephone calls, eighty-nine, or seventy-one percent, of the medium-sized cities responded.

Explanation of Variables

There are countless variables which could, in theory, be affecting water consumption. This study is an attempt to determine which ones are the most important in establishing consumption levels. A large number of physical and socio-economic variables have been selected for inclusion in the initial demand equation. Only a few are likely to remain significant. Most of these variables have been used in past studies, and many have been shown to determine water demand in other parts of the country.

The availability of necessary data was a large factor in selecting variables. The author's own survey and the 1970 census provided most of the data. Time constraints prevented the compilation of some desirable variables such as per capita lot area, which would have been the most accurate measure of irrigation needs.

One problem is that per capita daily water consumption covers the entire year. Indoor and outdoor water uses are averaged together to get this figure. Some variables may explain either indoor or outdoor use quite well, but lose their power when the average is taken.

An explanation of each variable is given in the following paragraphs including the source of each variable and its expected relationship to water consumption.

Daily Per Capita Residential Water Consumption (Q)

This is the dependent variable upon which this study focuses.

The consumption measure was generated by the survey discussed in the preceding section and an estimate of the population served by each water system created from census data. Since water consumption (not pumpage) was broken into four demand sectors, only residential water consumption was divided by the population served by the water system to find daily per capita water consumption. This corrects the error of some earlier studies that included the other demand sectors.

Population Served (P)

The population served by a municipal water system may easily diverge from the population of that city. If the system serves outlying subdivisions or neighboring towns the population of a city may underestimate population served. On the other hand, the presence of individual wells, which are very common in some areas, will tend to lower the population served below the city population. Since the number of residential service connections includes multiple family dwellings, apartment buildings, and trailer parks as single connections, this figure is of little use. For these reasons and because it is used to calculate per capita consumption, population served is one of the most important and most difficult variables to measure.

Population served was calculated through the use of census data. Sources of water were listed in the 1970 census for the housing units of each city. Housing units using water from individual wells and other sources were added and multipled by a density variable, the number of persons per occupied unit. This product, representing people not served by the public water system, was subtracted from the 1973 census population estimate, and the remainder was used as an estimate of population served.

Price

Again, several different measures of price were used in the regression equations. The price that is the most appropriate to use is the amount by which a customer can reduce his bill by reducing consumption by one unit. This is called the marginal cost or price.

The average daily residential water consumption for each town was divided by the number of residential service connections to get the average water consumption per service connections. This figure was multiplied by the number of days in the billing period to get average consumption per billing period, which shows onto which block of the rate structure the average customer would fall. That price is the marginal cost or price of water (MC_w) to the customer. Only towns with single block or declining block rate structures (and therefore positive marginal costs) were used. (Rate structures are discussed in a later section.)

Nearly all towns with water meters and sewer systems base their sewer charges on water consumption. This is because all water used in the home must go into the sewer system. Since much of the water used in the summer is for outdoor purposes, many towns base their sewer bills on winter water consumption. A customer who reduces his winter water consumption thus may save on his sewer costs as well as water costs.

Two more measures of price are thus indicated. Using the average water consumption per billing period, the marginal cost of sewer services per unit was found from the sewer rates structures. The marginal cost was then calculated a second time for sewer services in the summer. If the sewer charge is based on winter water consumption, marginal cost of sewer in the summer becomes zero. The price measures used were marginal cost of water and sewer in the winter ($MC_{w+s,w}$) and marginal cost of water and sewer in the summer ($MC_{w+s,s}$).

Finally, the average cost of water and sewer in the winter ($AC_{w+s,w}$) was tried as a price measure. Since most cities have a declining block rate structure, the first units of water purchased cost more. Combined with the common service charge or minimum demand charge, this average cost is usually higher than marginal cost. Since the customer cannot change this cost directly by changes in consumption, this price measure is much less meaningful economically. However, since it was used in several of the other demand studies, average price was included for comparison purposes.

For all these price measures, an inverse relationship with consumption is expected.

To test whether people were reacting to the size of their utility bills rather than the prices for these utilities, a dummy variable (X) was used. Towns with monthly billing periods were given a value of 0. Towns with quarterly billing periods received a value of 1.

Per Capita Income (Y)

The 1972 census estimates of per capita income were used. A positive relationship between consumption and per capita income is expected.

Value of Home (V)

The 1970 census provided estimates of median home value for each city. These values are given for owner-occupied homes, but are assumed to apply to rented houses equally. Since these values are outdated and were estimated by the homeowners themselves, they are undoubtedly different from market values today. An assumption is being made that home values have risen in the same proportion in all cities since 1970. A positive relationship with water consumption is anticipated since more water using appliances and bigger towns tend to accompany more valuable homes.

Persons per Residence (D)

The 1970 census also gave values for the number of persons per occupied housing unit. As this number increases, per capita water consumption is expected to decrease.

Education Level (E)

Some sort of educational index seems an appropriate sociological variable. The census provides the median number of school years completed by adults over age twenty-five for each community. Since education has a direct relationship to income, it should also have a positive correlation with consumption, just as income does.

Proportion of Rented Units (R)

From the total number of housing units and the number of rented units given in the 1970 census, the proportion of rented housing can be gauged. Its relation to consumption is not clear. From a price standpoint, a sizeable share of rented units have their water and sewer utilities paid by the landlord. This means the marginal cost to the renter is zero, and so a larger than average consumption would be expected. However, if a large share of rented units are apartments, the fact that they have little or no lawn could spell lower consumption. The relative weights of these opposing forces are unknown before testing.

Number of Bathrooms (L)

This information was also available from the census. All housing units were placed in one of four categories according to their number of bathrooms: zero or shared, one, one and a half, or two or more. For the purpose of this study zero or shared was assumed zero, and two or more was assumed to be two bathrooms. The average number of bathrooms for a house in each community was then calculated. It was thought that this measure was a good proxy for the number of water fixtures and thus the potential for indoor water consumption. A direct relation to consumption is expected.

Average Minimum Water Deficiency (W)

A climate variable should be included in any demand study of this type. The average minimum water deficiency (in inches per season) shows the amount by which evapotranspiration exceeds precipitation. It should show the relative need for irrigation and includes such variables as rainfall, temperature, sunlight, and wind. Consumption can be expected to increase as the water deficiency increases.

Proportion of Youths (C)

Some water experts have speculated that children are not as conservation conscious as adults and tend to consume more water. At least one demand study (Turnovsky, 1969) has verified this. The number of people under eighteen years of age was divided by the total population to figure the proportion of youths. The relationship to consumption should be direct.

Model Development and Statistical Results

Multiple regression models using ordinary least squares techniques were created to examine the relationship between residential water consumption and the assumed explanatory variables. The variables have already been defined and discussed. They are listed with their symbols in Table 1. Since only one price measure will be used at a time, there are eleven independent variables in each model. Mostly for reasons of data availability, the number of towns used in the models was reduced to an unbiased sample of seventy-five.

First a linear model was tested. The general form is:

$$Q = B_o + B_p P + B_{mc} MC + B_x X + B_y Y + B_v V + B_d D + B_e E = B_r R + B_l L + B_w W + B_c C + e$$

where Q_i is the dependent variable, B_o represents the constant term, the other B's are estimated regression coefficients for their respective independent variables, and e represents the error term.

> "The estimated regression coefficients in a multiple regression are interpreted as partial slopes. They try to answer the question: When X_k, the kth describing variable, changes by one unit and all the other describing variables are held constant (in a statistical sense), how much change is expected in Q? The answer is B_k units."[1/]

Three criteria were mainly used in selecting each model. The student's T test was used to judge the significance of the overall model. Finally, R^2, or the proportion of variation explained by the model, was used for judging the quality of the overall fit of the describing variables in predicting Q.

At this point it should be mentioned that the marginal cost of water and sewer in the winter proved the best price measure, as was expected. Although all the price measures were tried, only models using $MC_{wts,w}$ will be listed. The use of other price measures will be discussed later.

[1/] Tufte, Edward R., Data Analysis for Politics and Policy, Prentice-Hall, Englewood Cliffs, N.J., 1974, p. 138.

Table 1. Results of Variables Used in the Model.

Variable Used	Symbol	Mean	STD Dev	Min	Max
Consumption/capita/day (survey)	Q_1	78.7	32.7	39.4	228.0
Consumption/ capita/day (Dept. Health)	Q_2	79.7	79.4	16.0	726.2
Population Served	P	7,517	5,902	84.2	23,253.4
Marginal Cost, water ($/1000 gal.)	MC_w	$.551	.236	$.150	$1.35
Marginal Cost, water + sewer, winter	$MC_{w+s,\ w}$	$.849	.390	$.150	$1.95
Marginal Cost, water + sewer, summer	$MC_{w+s,\ s}$	$.692	.371	$.150	$1.725
Average Cost, water + sewer, winter	$AC_{w+s,\ w}$	$1.128	.342	.389	$2.144
Billing Period (Dummy)	X	.573	.498	0	1
1972 Per Capita Income	Y	$3,641	774.4	$2,330	$5,983
Value of Homes	V	$17,407	5,605	$7,000	$30,100
Persons per Residence	D	3.22	.49	2.7	4.7
Education Level	E	12.05	.701	9.5	13.8
Portion of Units Rented	R	2.46%	8.7	3.9%	51.8%
Number of Bathrooms	L	1.173	.096	.987	1.607
Average Minimum Water Deficiency	W	8.91	.93	6	11
Proportion of Youths	C	22.8%	9.67	11.8	54.1%

The estimated linear equation derived by the least squares method is:

$$\begin{array}{l} Q_1 = 170.43 - .0041P - 18.88MC_{w+s,\ w} + 3.30X \\ \qquad (109.95)\ (.0013)\ \ (0.44)\qquad\qquad (7.97) \\ \quad + .0087Y + .0014V - 3.69D - 2.20E - 35.12R \\ \qquad (.0095)\ \ (.0017)\ (16.27)\ \ (6.98)\ \ (68.79) \\ \quad - 83.82L - .49W + 2.04C \\ \qquad (66.94)\ (4.02)\ \ ).84) \end{array}$$

The standard error of the regression coefficients are given below in parentheses. F^{11}_{63} + 2.54 which is significant at the .01 level. $R^2 = .31$. However, many of the independent variables are not significant. They will be discussed later.

The final linear demand model selected was:

$$\begin{array}{l} Q_1 = 50.82 - .0043P - 21.94MC_{w+s,w} + .0080Y + 2.19C \\ \qquad (20.21)\ \ (00.0)\ \ (8.63)\qquad\qquad (.0044)\ \ (.63) \end{array}$$

All variables have the expected sign. All are significant at less than the .02 level except for income which is significant at the .076 level. The overall model is significant at less than the .0001 level with $F^4_{70} = 6.93$. The model explains 28% of the variations in Q_1. The price elasticity of demand at the mean is .37.

Next a logarithmic model was introduced to account for possible non-linearity in some explanatory variables. The general model is:

$$\begin{array}{l} \text{Log } Q_1 = B_o + B_p \text{ Log } P + B_{mc} \text{ Log } MC + B_x \text{ Log } X + B_y \text{ Log } Y + B_d \text{ Log } D \\ \quad + B_e \text{ Log } E + B_r \text{ Log } R + B_l \text{ Log } L + B_w \text{ Log } W + B_c \text{ Log } C + e \end{array}$$

The corresponding logarithmic equation is:

$$\begin{array}{l} \text{Log } Q_1 = 5.02 = .27 \text{ Log } P - .17 \text{ Log } MC_{w+s,\ w} - .0023 \text{ Log } X \\ \qquad\qquad (2.83)\ (.063)\qquad (.075)\qquad\qquad (.083) \\ \qquad\quad + .086 \text{ Log } Y + .22 \text{ Log } D - .11 \text{ Log } E + .094 \text{ Log } R \\ \qquad\qquad (.39)\qquad\qquad (.58)\qquad\qquad (.87)\qquad\qquad (.13) \\ \qquad\quad + .25 \text{ Log } L - .069 \text{ Log } W + .53 \text{ Log } C \\ \qquad\qquad (.83)\qquad\qquad (.35)\qquad\qquad (.16) \end{array}$$

The standard errors of the regression coefficients are again in parentheses. An $F^{11}_{63} = 3.29$ means the overall model is significant at the .001 level, and the R^2 equals .36. Many variables are not significant. When they are deleted the final logarithmic demand model is:

$$\begin{array}{llll} \text{Log } Q_1 = 4.86 & - .26 \text{ Log } P & - .1535 \text{ Log } MC_{w+s,\ w} & + .54 \text{ Log } C \\ \quad\ (.35) & \quad (.051) & \quad (.066) & \quad (.12) \end{array}$$

All variables have the expected sign, and all are significant at less than the .025 level. The F_2value of 13.1 is extremely significant at less than the .001 level. The R^2 is still .36, so deletion of the insignificant variables has not hurt the explaining power of the model. The price elasticity of demand is constant at -.15.

DISCUSSION

Performance of the Variables

There were only two unexpected signs on the variables in the linear model. Both can be attributed to problems of multicollinearity. Per capita income, the value of homes, education level, and the number of bathrooms are all measures of economic status, and all show a degree of intercorrelation on the correlation matrix. In regression models with these circumstances, it is not uncommon for the related variables to show oppostie signs. In this case income and home value have the expected positive relationship with consumption, while the number of bathrooms and the education level show negative signs. The beta (B) values for income and home value fall when the other two variables are removed from the equation. Also, income becomes less significant when the number of bathrooms is removed from the model, a sign that the two variables with opposite signs were together explaining the role of economic status. So in all likelihood, all four measures of economic status have a direct effect on water consumption. The removal of all but per capita income reduced the R^2 by .019.

It was hoped that the value of homes would also serve as a proxy for the size of lots and thus the irrigable lawn area. It might also be a measure of the number of inside water-using devices. The data for this variable was rather questionable. It was the median home value from the 1970 census. Since the values were compiled from estimates by the homeowners themselves, this is one source of error. Another is that property values have changed drastically since 1970. Using 1970 values assumes that the increases have been proportional across the state. The assumption is demonstrably false. Better data, such as from property tax records, might have made this variable significant.

The proportion of housing units that are rented did not play an important role in either model. In fact, the sign on this variable changed from the linear to the log model. However, since the simple correlation coefficient with consumption is -.27, the effect of the proportion of units rented on consumption can be assumed negative. This means that the effect of having a smaller per capita lot area with rented units outweights the effect of having free water from the landlord paying the water bill.

The average minimum water deficiency per growing season was disappointingly insignificant in both models. This could be due to the values themselves for this variable. They only range from six to eleven inches, and are interger values derived from a very large scale map. This could be too small a range to be effective in multiple regression.

The author does not feel that the poor performance of water deficiency should be used to discount the effect of climate on residential water consumption. In theory, this variable was a superior measure of climatic conditions compared to other commonly used variables. But for a regression model, perhaps average rainfall, average evapotranspiration, length of growing season, or the average number of rainy days in the growing season would have more power in explaining water consumption. In a state where rainfall varies by fifty percent, the demand for lawn irrigation water should vary tremendously, unless it is counteracted by an increasing tolerance for brown lawns in the more arid, Western regions.

Of the variables in the final linear model, per capita income was the least significant. In fact, it was not included in the final logarithmic model. Again this could be due in part to variations in community income levels since this variable was measured in 1972. Per capita income accounts for .034 of the proportion of variations in consumption explained by the model.

The per capita income variable results in an income elasticity of .37, which means that a one percent increase in income would result in a .37% increase in water consumption. This value is not surprising considering the rather low prices of water and the very low proportion of income which is used to purchase water by most households. The cost of water is so low that it is not apt to be considered a luxury good except when used in huge quantities or as a complement to other luxury items. Since Minnesota is an area rich in water resources with over 20,000 lakes, the demand for water for swimming pools is certainly much less than in the Southwest U.S. If the demand for water for recreational purposes could somehow be measured, the income elasticity of demand would likely exceed 1.0. Water would then be a superior, instead of a normal good. The value of .37 fits quite well with the income elasticities of past demand studies.

The proportion of persons under eighteen years of age in each city was another significant demand determinant. Since this variable was expressed in percentages, the beta value means that a town whose children account for one percent more of the population will have a per capita water consumption of 2.18 gallons more than another town. This is a clear indication children cause higher water consumption patterns than do adults. If present population trends continue, the proportion of youths can be expected to drop in the future and water consumption should fall with it. However, water policymakers can in no way control this factor. In the linear model, the presence of the proportion of youths increased the R^2 by more than .06.

The size of the population served by the water system had a very strong positive relationship with residential water consumption. This was the most significant variable in the linear model and also the best for explaining residential water consumption, since it accounts for nearly ten percent of the variations in water consumption. If the population served by a water system increases by one thousand persons, its per capita water consumption decreases by 4.3 gallons.

The reasons for this relationship are unclear to the author. It was thought that the larger cities had a larger proportion of units rented, and that this caused the negative effect on consumption. However, a regression of units rented against population showed that these two variables were completely unrelated. A good possibility is that lawns are smaller in larger cities, and so the per capita use of water for sprinkling decreases with city size. It is also conceivable that the peak demands are so aggrevated by larger populations that water pressure falls, and involuntary water conservation results.

The Effect of Price

Price is the only variable in the final models which can be easily altered by decisionmakers, and so it is of special interest. Its graphical relationship with consumption constitutes a demand curve.

First, the performance of the other price measures will be compared to that of the marginal cost of water and sewer in the winter ($MC_{w+s,w}$). Since the consumption measure was averaged over the seasons, one might expect the marginal cost of water and sewer in the summer ($MC_{w+s,s}$) to do just as well as the cost in the winter. However, this was not the case, and the $MC_{w+s,s}$ was not even a significant variable with the result that the R^2 fell substantially. Since sewer charges are often based only on winter consumption, the marginal cost of sewer in the summer is zero for many towns. This made $MC_{w+s,s}$ differ widely from town to town. Since it is not significant in explaining consumption, one could infer that people either are not aware of or else are not reacting to this seasonal change in marginal cost.

Models were also fitted with the marginal cost of water (MC_w) as the price measure. The same linear and logarithmic models resulted except that MC_w was only significant at the .12 and .17 levels respectively. The price elasticities were -.15 and -.14. These values cannot be considered significantly different from the values of -.24 and -.15 generated by $MC_{w+s,w}$.[1] Therefore one should not discount the possibility that MC_w, and not $MC_{w+s,w}$, is the price measure that people are aware of, even though MC_w was less significant in the models.

Since many of the past water demand studies used average cost as the price measure, it was also tried in this effort. The average cost of water and sewer in the winter ($AC_{w+s,w}$) was inserted into the initial regression models. Home value replaced income in the final linear model, and both it and average cost were only significant at the .066 level. The R^2 was .26, and the price elasticity was -.27. The logrithmic model was similar to the one with $MC_{w+s,w}$. An R^2 of .37 and an elasticity of -.31 resulted.

The elasticities, especially in the logarithmic model, are higher than those from the marginal cost model. This makes some theoretical sense since the average cost of water to the consumer tends to be higher than the marginal cost. The mean $AC_{w+s,w}$ is \$1.128 as opposed to \$.849 for the mean $MC_{w+s,w}$. If the demand curve is linear or nearly so,

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[1] A more formal statistical comparison using confidence intervals computed from the standard error would be very difficult. Standard errors of ratios such as an elasticity are not easily found. The jack knife technique would be most applicable, but the sample size of 75 makes this prohibitive without the aid of a computer programmer.

one would expect the price elasticity to increase with price.

However, these values from $AC_{w+s,w}$ are not the relevant elasticities. The price elasticity of demand shows how demand will respond to changes in price. It is the proportional change in demand divided by the proportional change in price. Yet the average cost cannot be changed directly. A change in average cost requires that total cost change by the difference in average cost times the amount of water used. This will coincide with the change in total cost from reduced consumption only by accident. Average cost is simply not the correct price measure in analyzing economic behavior. Since average cost cannot be changed directly, its price elasticity is also not relevant. Nevertheless the values will be useful in making comparisons to other price elasticity work.

The marginal cost of water and sewer in the winter produced price elasticities of -.24 and -.15 with linear and logarithmic models. Price accounted for about 6% and 10% of the variations in water consumption. The hypothesis that price has a significant effect on residential water consumption has not been proven false. And while a standard error will not be calculated for the price elasticities, confidence can be placed on the statement that it differs significantly from zero.

Comparison to Other Studies

The elasticities computed from this set of data compare rather well with the literature on this subject, as can be seen in Table 2 on the following pages. Although these estimates tend to be on the low end of the range of previous results, they are congruous with at least half of the past estimates. As with this study, standard error of the elasticity estimates are not given, so more formal comparisons are impossible. It is worthwhile to note that of the studies that produced much higher elasticities than this one, six used average instead of marginal price. Since average price, both in theory and in this study, exhibits a higher price elasticity than marginal price, this can be taken as further support for the estimates of this research.

The author feels that any bias in these elasticity estimates is in a downward direction. The drier than normal weather during which this study was conducted probably increased water consumption irrespective of price. Some water systems were in danger of exceeding their capacities and voluntary conservation campaigns may have held down consumption where there were no economic incentives to do so. Also geographical and, hence, climatic differences probably lead to people reacting differently to a certain price level in different areas. So the cities of western Minnesota may experience high consumption levels with relatively high water prices. A significant climatic and/or weather variable in the models would likely result in an increase in price elasticity. The price elasticity estimate of -.15 should therefore be considered a lower bound.

Table 2. Water Demand Studies

Investigator	Year	Type of Analysis	Price Elasticity	Income Elasticity	Remarks
Metcalf	1926	29 Waterworks Systems Cross-sectional	-.65		Average Price
Gottlieb	1947-9	Illinois Cross-sectional	-.27		
Larson and Hudson, Jr.	1951	8 Illinois Communities Cross-sectional		.70	
Seidel and Bauman	1955	441 American Cities Cross-sectional	-.12 to -1.0		Varies with Price
Fourt	1955	34 American Cities Cross-Sectional	-.39		Marginal Price
Renshaw	1955	21 Water Service Systems	-.45		
Hanson and Hudson, Jr.	1956	8 Illinois Communities Cross-sectional		.55	
Gottlieb	1957	Kansas Cross-sectional	-.66 to -.124	.28 to .58	Average Price
		Speculation	-.4 to -.65	.3 to .6	Ep Varies with City Siz
Milliman	1963	Speculation	-.3 to -.4		
Wong et al.	1963	Northeastern Illinois Cross-sectional	.01 to -.72		
Headley	1963	S.F. - Oakland 1950-59 Time-series		.00 to .40	
Gardner & Schick	1964	43 Northern Utah Water Systems Cross-sectional	-.77		Ave. price; logarithmic

Table 2. (Continued)

Investigator	Year	Type of Analysis	Price Elasticity	Income Elasticity	Remarks
Ware & North	1965	14 Georgia Communities Cross-sectional	-.67 -.61		Ave. price; linear Logarithmic
Flack	1965	54 Western Cities Cross-sectional	-.12 to -1.0		Varied with Price
Bain, Caves, Margolis	1966	41 California Cities Cross-sectional	-1.099		Average Price
Howe & Linaweaver	1961-6	39 residential areas in U.S. Cross-sectional	-.231	.319	Marginal price, in-house use
			-.702	.429	Sprinkling, West
			-1.57	1.45	Sprinkling, East
Conley	1967	24 S. California Communities Cross-sectional	-1.02 to -1.09		
Turnousky	1969	19 Massachusetts towns Cross-sectional	-.05 to -.40		
Grima	1970	91 Observations Cross-sectional	-.93	.56	
Wong	1970	Chicago 1951-1961 Time-series	-.02 to -.28	.20 to .26	
		103 N. Illinois cities Cross-sectional	-.26 to -.82	.48 to 1.03	Varied with city size
Hittman Assoc.	1970	41 Large Water Systems Cross-sectional	-.44		Marginal price
Hoffman and Primeaux, Jr.	1971	1[illegible] N. Mississippi Cities Cross-sectional	-.26 -.15	.24 .24	Ave. price linear Logarithmic

Table 2. (Continued)

Investigator	Year	Type of Analysis	Price Elasticity	Income Elasticity	Remarks
Pope, Stepp, Lytle	1965-71	4 South Carolina Cities			Domestic use, varies by city
		Time-series	-.182 to -.512		1st year after price change
			.094 to -.318		2nd year
			-.156 to -.674		irrigators, 1st year
			.317 to -.452		2nd year after price change
			-.124 to -.357		non-irrigators, 1st year
			-.017 to -.211		2nd year after price change
Grunewald et al.	1972	150 Kentucky water dist.	-.92	.18	Average price
Lauria & Chiang	1975	89 N. Carolina Communities		.03	
Gardner	1975	75 Minn. Medium-sized cities	-.24 -.15	.37	Marginal price, linear logarithmic

Adapted from Wong, 1970 and Hittman, Associates, 1970

The Shape of the Demand Curve

That estimate should also be considered a lower boundary because it came from a logarithmic model. With such a curvilinear demand function, the price elasticity of demand is constant throughout its length. In contrast, a perfectly linear demand function will vary from perfect inelasticity at price zero to infinite elasticity at that price which causes demand to be zero. The demand curve for water will probably not resemble either of these two extremes. A demand function with some curvature or at least kinks was hypothesized in the introduction. As price fell, demand was thought to increase disproportionately as water uses of less and less utility become feasible. At least one kink in the demand function should exist at extremely low consumption levels. Subsistence amounts of per capita water would be needed at any price, so one would imagine the demand curve to become vertical at some very low consumption level.

The value of -.24 for the price elasticity in the linear demand model is the point elasticity at the mean price of $.849. Since $MC_{w+s,w}$ ranges from $.15 to $1.95, some further information may be gained from an examination of arc elasticities in either direction away from the mean. If the demand function is linear, at least in this section, then the arc elasticity from the mean downward should be less elastic than -.24, and the arc elasticity upward from the mean should be more elastic than -.24.

First the arc elasticity upward from the mean was tested. Those fourteen towns with $MC_{w+s,w}$ greater than or equal to $1.25 were used as the upper point. The jackknife technique was used to obtain an arc elasticity estimate and an estimate of its standard error. The jackknife technique is useful as a bias reduction method and provides a simple way of estimating the standard error of the estimate.[1] The elasticity was estimated at -.297 with a standard error of -.006 and is significantly more elastic than the point elasticity at the mean of -.24.

Similarly the twelve towns whose $MC_{w+s,w}$ was less than $.45 were used to compute an arc elasticity downward from the mean. It was reckoned at -.186 with a standard error of .1126. This makes a 95% confidence interval of -.478 to .106. So although the value is lower than the mean, one cannot say with much confidence that it is significantly lower.

So the price elasticity of demand does increase as price is raised while the effect of price decreases is uncertain. One could speculate that in these towns with the lowest water prices, it is voluntary conservation, and not economic constraints, that limits water consumption. The results of this arc elasticity experiment contradict the hypothesis of a curvilinear demand curve. Indeed, they seem to point to a linear demand curve within the price range examined.

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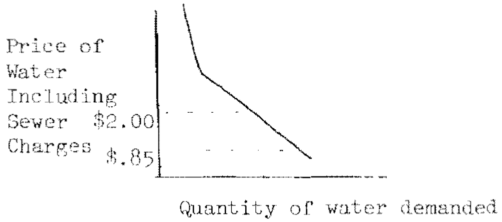
[1] Mosteller, F., and J.W. Tukey, Data Analysis, Including Statistics, in Lindzey, G., and E. Aronson (eds) Revised Handbook of Social Psychology, Addison and Wesley, 1968.

However, there is some mild, but inconclusive, support for a curved demand function in that the R^2 for the logarithmic model is .36 as opposed to .28 for the linear model. This is not a significant difference, but most of the increase is taken by an increased role of $MC_{w+s,w}$ in explaining consumption differences. From the results of this study, one might imagine a residential water demand function for Minnesota cities that looks something like this:

Figure 2. Hypothetical Demand Curve for Water.



Policy Implications

A price elasticity in the range of -.15 to -.24 is quite inelastic. An elasticity between 0 and -1 means that a price increase will generate more revenue for the utility than is lost to decreased consumption. Therefore, water utilities can raise price to avoid financial difficulties. By following a marginal cost rate structure, water systems should not need outside revenue to accomodate expansions of the system.

However, the price elasticity is significantly different from zero. There should be a noticeable effect of reduced consumption when the marginal price of water is increased. There are sound economic incentives to place this marginal price at the marginal cost to society of producing the water. Moreover, if the price of water is raised again to match an increasing marginal cost, the price elasticity of demand will rise with it and produce even larger conservation effects.

The Strength of the Model

The explaining power of the models generated by this study is rather low. The linear model accounted for 28% and the logarithmic 36% of the variations in residential water consumption between towns. The majority of the variations is left unexplained. This means either there are other variables which explain most of the variations in water use or there were errors in the data for the variables that were included in this study.

The possibility of having omitted an important explaining variable seems small. Nearly all the variables which were significant in other water demand studies were included here. In the case of such variables as median home value and average per capita income, it is possible that the values used deviated substantially from the real norms. And in the case of climatic differences, some variable other than average minimum water deficiency might have better explained consumption. Nor should one discount the chance that man is not as economic a creature as social scientists often assume. Some hard-to-measure variable, such as social consciousness, may be the controlling factor over residential water consumption.

There are several possible sources of distortion in the data used. The simplest is that the aggregation of such socio-economic measures as income, education, or home value renders the data nearly meaningless. Values at either extreme are lost in the process of averaging. Thus two cities may have the same mean value, but widely divergent variances. The resulting consumption figures are aggregated also. In short, the cross-sectional method assumes a homogeneity in the population which cannot possibly exist. The more relevant question is by what amount does each town diverge from this hypothetical sameness?

Geographical heterogeniety is a similar problem. While climatic differences, for whatever reason, were unable to significantly explain differences in consumption, they may be distorting price effects. The price elasticity for outdoor water demand has been shown to be much less elastic in the West than Eastern U.S. (Howe and Lineaweaver, 1967). On a statewide basis, sprinkling demand in western Minnesota may remain high despite the relatively higher prices of that area. Most of the water demand studies were performed in areas of more uniform climate.

Next, there could have been changes in some of the variables which used 1970 values. This would include the proportion of youths, the value of homes, the number of persons per residence, the number of bathrooms, the education level, and the population served. This last variable is particularly suceptible to data changes. Recalling that population served was the 1973 population of each city with the number of homes using a private water source times the persons per residence value removed, population served clearly depends on the water source distribution. The dependence on individual wells could decrease as homes hook up to the public system, but it is unlikely to increase. Recent dry weather since 1970 may have hastened this trend.

Expansions of the water system will also change the data for population served. Expansions must cause a distortion, because the population served and the water source distribution must change. Expansions of the city limits would have a similar effect. Those water systems which serve people outside the city limits or in outlying towns may have a population served larger than the city population. Since the computation of population served in this study limits the value to the city population, consumption values in some cases must have been overstated.

This is why population served is such a key variable. Not only was it a major explaining variable, but it also figures in the value for per capita daily water consumption. Changes in variables since this time of measurement could easily lower the R^2.

Another factor which would dampen the explaining power of the model is conservation. This could be voluntary as when cities call for a reduction in sprinkling. Conservation could also be involuntary by reductions in water pressure which would lessen the possible rate of water use. This issue could have been examined by questions on the survey regarding conservation campaigns and the average and extremes of water pressure.

Finally the weather in 1975 and 1976, when most of the consumption data was taken, may be affecting the model. Since these years were far drier than normal, sprinkling demand was almost certainly higher. Thus water use was likely mch less elastic than in other years. The price effect would be diminished as people used water to keep their lawns, shrubs and even trees alive regardless of cost.

The next section examines rate structures used within the state of Minnesota to see what their effect is on conservation and to take a closer look at the marginal price with these price elasticities in mind.

RATE STRUCTURES

Since the survey encompassed all public water systems in Minnesota municipalities, this examination of rate structures will not be limited to medium-sized cities. Before displaying the results of the statewide survey, a brief discussion of rate forms seems in order. Some terms will be defined, criteria for evaluating rate forms will be mentioned, and the common rate forms will be discussed in some detail along with some possible inequities.

Rate Structure: Describes how revenues are collected from municipal customers. It includes both rate form and rate levels.

Rate Form: Refers to the shape of the rate structure and describes the manner by which price varies. This could be by amount of consumption, by demand sector, location, time, persons in residence, or even by the number of plumbing fixtures. The four most common rate forms are a flat charge, a single block, declining blocks, or increasing blocks.

Rate Level: Indicates the amount or magnitude of a rate at a specific place or range on the rate form, e.g. $.50 per thousand gallons or $5.00 per month for residential users.

Criteria for Evaluating Rate Forms

There are several things to keep in mind when evaluating different rate forms. Some have been of traditional concern, and others are only now receiving the attention they deserve. The yardstick by which rate forms have historically been measured is their ability to meet the revenue requirements. Sometimes a rate form was only required to raise enough revenue to meet operating costs, but more recently debt retirement and other capital costs are also included so that the water utility can be completely self-sufficient.

The source of recent controversy in the area of rate structures is the insistence by some that rate forms also meet a requirement of economic efficiency. Economists have been observing that many rate forms do not allocate resources in a way that will maximize the benefits to society. This is the rationale for marginal cost pricing.

A similar conflict arises in the traditional belief that rate structures should not discriminate. The idea of charging a different price for different groups of customers seems to run counter to the democratic history of this nation. However, an overriding criterion seems to be that a rate form should not foster any social inequities. There may well be inequity in some of the common rate forms that can most easily be cured by price discrimination. The principle that he who reaps the benefits shall pay the costs also seems quite democratic. Nevertheless, popular belief will not be swayed until the economic foundations of these new ideas are publicly exposed.

So at present, the traditional rate forms can be defended on the grounds of practicality. They are understandable, publicly acceptable and feasible to implement. One other potential criterion for evaluation is rate stability. Some stability at least within a certain range is important because investors need information for planning decisions. Of course, the snail-like adjustments of rate levels by most water utilities may provide more than adequate stability.

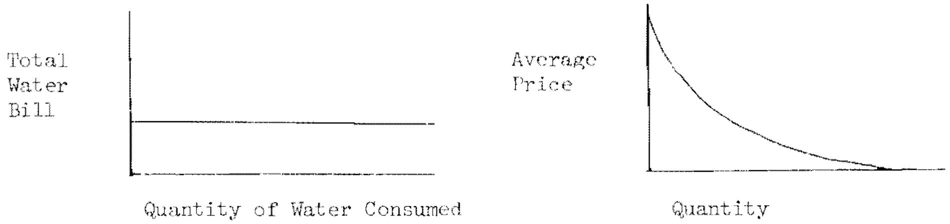
A final criterion for evaluating rate structures has just recently come to attention. Increasing scarcity of high quality water has made conservation an important issue. The ability of a rate structure to induce conservation efforts is a social objective of increasing stature.

Common Rate Forms

Flat Charge: Under this rate form each customer pays one price for any amount of water consumed; there is no limit on the amount used. The total water bill does not vary with the amount used, and therefore the average price for water (or sewer) declines as more is consumed as is shown in Figure 3. There is no incentive to conserve because the marginal cost of water to the consumer is zero. The water utility multiplies the average cost of producing water times the expected amount of use per customer to obtain the amount of the charge. This is the type of rate form which must be used when a city does not have residential water meters, e.g. New York City or many small Minnesota towns.

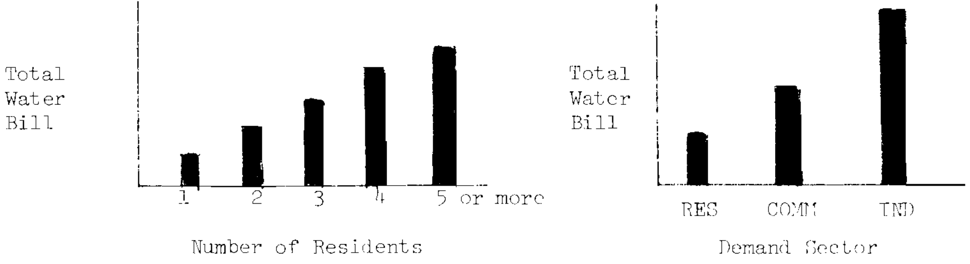
Obviously this is the least desireable of rate forms. It is completely inequitable in that the size of the water bill has absolutely no relationship to the amount of water used. Those with large houses, large families, or many water-using appliances are subsidized by people with more moderate consumption patterns.

Figure 3. Flat Charge Rate Form.



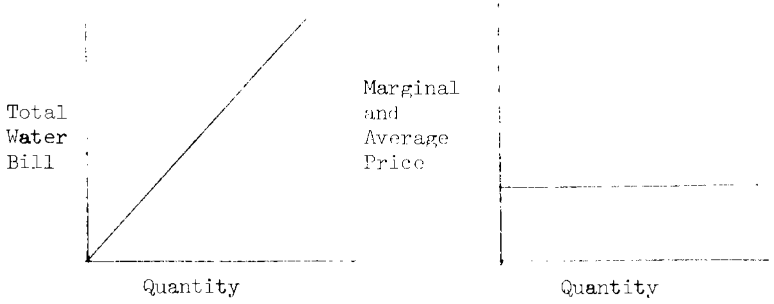
Sometimes flat charges will be made to vary with the number of residents, the number of plumbing fixtures, and/or by the demand sector (See Figure 4). The first two install some measure of equity into the rate while the latter is by far the most common.

Figure 4. Total Water Bill as Related to Number of Residents and Demand Sector.



Single Block: With this rate form, the price per unit of water is constant no matter how much water is consumed (see Figure 5). Total cost to the customer increases with consumption, and so there is an economic incentive to conserve. Since there is only one price, this incentive remains constant. If the single block is set to match the marginal cost, this rate form can be both efficient and equitable. Varying costs for different consumer classes might mean a variety of single blocks, however. Of course, there must be some kind of metering system since the water bill varies by the amount consumed.

Figure 5. Single Block Rate Form



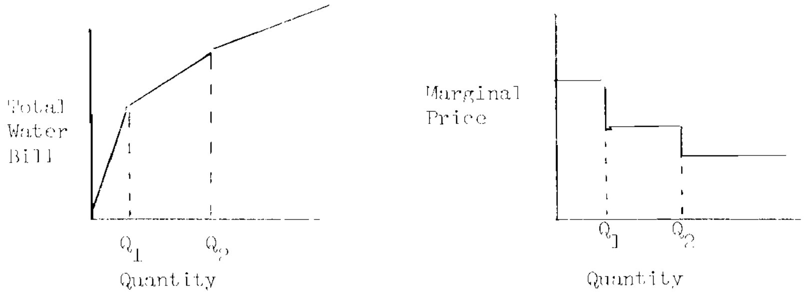
Declining Blocks: Under this rate form, the price unit decreases in a stepwise manner with the amount purchased (see Figure 6). The consumer pays one price, or rate level, for a certain quantity of water and a lower price for additional use. The total cost of water to the consumer increases, but at a decreasing rate. The incentive for conservation decreases as lower and lower rate levels are reached.

This is probably the most common rate form used by public utilities in the United States today. It is recommended by the American Waterworks Association (AWWA). This is a "promotional" rate form that was originally used by utilities to encourage growth in demand in order to make full use of system capacity. The current rationale for declining blocks is that large customers deserve lower prices because of economies of scale in well and reservoir construction and because of lower distribution costs. In view of the increasing scarcity of high quality water, the ramifications of this rate form need to be examined more closely.

Before any blanket judgements are made, it should be remembered that declining block rate structures can vary tremendously. The quantities at which different blocks begin are quite important. They may be placed so as to encourage water waste by residential users, or they may simply give a break to extremely large customers. An excessively large number of blocks can cause unnecessary confusion and difficulty in billing.

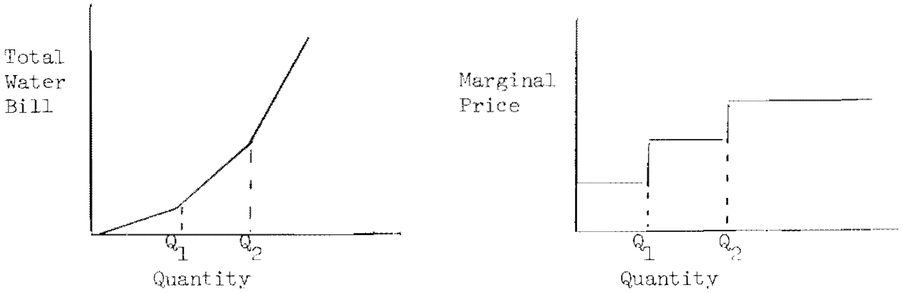
The ratio of highest to lowest rate levels also conveys information about the rate structure. Declining blocks range on a continuum from a very nearly single block rate form to blatant subsidization of large customers. If this ratio is to be justified on the economic grounds of marginal cost, then the costs of delivering water should vary by this same ratio.

Figure 6. Declining Block Rate Form.



Increasing Blocks: This is the opposite of declining blocks in that the price per unit increases in a stepwise fashion with the amount purchased (see Figure 7). The total cost of water increases at an increasing rate. The incentive to conserve increases as higher rate levels are reached. This rate form is rarely used by utilities. The scarcity may be justified since it is doubtful whether the marginal cost of production follows this pattern. With lower distribution costs for large customers, there seem to be serious inequities with this rate form. However, the proposed "lifeline" rates, which offer minimal amounts of water at a nominal cost, would fall into this rate form.

Figure 7. Increasing Block Rate Form.



Additional Charges for Utility Use

Service Charge: This is a separate charge from the rate structure for the privilege of purchasing water from the municipality. The privilege is that each customer has an open-ended contract with the utility to purchase as much or as little as desired. The utility must maintain excess capacity for those demand peaks when many want to consume at the same time. This excess capacity costs money to build and maintain; this is the rationale for the service charge. It could also be construed as a charge for fire protection and the use of water hydrants. In addition, there is a legitimate economic argument that all fixed costs should be incorporated into the service charge, and that the commodity charge which is proportional to water use should only include variable costs. This will be discussed in the following section.

The service charge is sometimes incorporated into or disguised in the form of a minimum charge or minimum demand charge. Any of these can be added to a rate structure.

Minimum Demand Charge: This is a flat charge for the first quantity of water. The price per unit is usually much higher for this initial amount, and so the minimum demand charge may be thought to contain the service charge. The initial amount of water (or sewage) included in this charge may be relatively small, such as one thousand gallons, or larger, such as ten thousand gallons.

There is an incentive to use this first amount since the customer will be charged for it anyway. The marginal price is zero after the first gallon and up to the initial amount, so the minimum demand charge becomes more inequitable as the quantity of water it includes grows larger. The probability of altering consumer behavior grows in this manner also. A minimum demand charge is recommended by the AWWA along with a declining block rate form.

Minimum Charge: This is nearly identical to the minimum demand charge, but the wording is different. A rate structure is given with the further stipulation that there is a minimum amount which will be charged. One difference from the minimum demand charge is that a minimum charge need not come out to a whole number of units purchased, e.g., water costs $.75 per thousand gallons with a minimum charge of $2.00.

Billing Period: This indicates how often consumption will be measured and utility bills will be calculated. Normal periods are monthly, quarterly, semi-annually, or annually. The length of the billing period can affect the utility bill if declining or increasing blocks are used in the rate structure.

Rate Structures in Minnesota

This section summarizes the salient characteristics of 327 water utilities and 284 sewer utilities in Minnesota communities of all sizes. They were grouped into small towns with a 1970 population less than 2,500, medium-sized cities of 2,500 to 25,000 people, and large cities with greater populations.

The sewer and water utilities were first categorized by their rate forms. Table 3 and Figures 8 and 9 display this information by city size. Note that rate forms A-D are all variations of the single block, E-H are declining block rate forms, and J and K are flat charges.

Declining blocks compose the majority of rate forms in water utilities of all sizes, but particularly in 86% of the medium-sized cities. The minimum demand charge is the most popular variety of this form. Service charges are prevalent only in the large communities.

Of the remainder of the water rate forms, note that the incidence of single block forms increases with city size. Conversely, the proportion of flat charge rates decreases as city size increases. This can be easily explained as it is the smallest towns which still lack water meters. The increasing block rate form is a rarity in either water or sewer rates.

The category of "other" rate forms mostly comprises oddities which have both increases and decreases in rate levels. There is no apparent economic justification for these forms.

A somewhat different distribution of rate forms exists for sewer systems. The most striking characteristic is that flat charges are the most common rate form. Since they are far more common than with water utilities, one can conclude that there are many cities with water meters which charge flat rates. The failure to use proportional rates of some kind when meters are present is a waste of technology, not to mention the promotion of social inequity and economic inefficiency.

Medium-sized towns have comparatively fewer flat rate charges and more declining block rates. This can be explained by the distribution of water rate forms, because many sewer rates are expressed as a proportion of the water bill.

Again increasing block rates are nearly absent, and single blocks are more common in the larger cities. There is a tendency for single block rates to be accompanied by a minimum charge in the sewer rate forms.

Next some statistics concerning rate levels will be analyzed. Tables 4 through 7 display rate structure statistics for small, medium, and large-sized cities as well as statewide figures.

Looking first at single block rates, one notices a trend for rates to increase as city size decreases in both water and sewer rates. Water single blocks increase from $.46 to $.47 to $.645; sewer rates rise from

Table 3.

Frequency of water and sewer rate forms, comparison by city size

	WATER				SEWER			
Rate form	small cities%	medium cities%	large cities%	Total%	small cities%	medium cities%	large cities%	Total%
A	2.7	5.4	28.0	4.8	1.1	7.0	11.1	3.4
B	0.0	1.0	5.5	.6	.5	4.3	0.0	1.7
C	.9	0.0	0.0	.6	1.1	4.3	5.5	2.4
D	.9	3.3	5.5	1.8	2.7	7.0	0.0	3.8
E	10.3	15.0	0.0	11.1	4.4	11.0	5.5	6.5
F	.9	9.0	16.6	3.9	1.1	2.0	5.5	1.7
G	.9	11.0	11.1	4.2	0.0	4.4	5.5	1.7
H	47.8	51.0	33.3	47.9	27.9	22.0	17.1	25.1
I	.9	0.0	0.0	.6	.5	1.0	0.0	.7
J	27.7	4.3	0.0	19.7	57.4	37.0	55.8	50.0
K	4.9	0.0	0.0	3.3	1.1	0.0	0.0	.7
L	2.1	0.0	0.0	1.5	2.3	0.0	0.0	1.4

KEY FOR RATE FORMS

A - Single block

B - Service charge plus single block

C - Single block with a minimum charge

D - Minimum demand charge with a single block

E - Declining blocks

F - Service charge plus declining blocks

G - Declining blocks with a minimum charge

H - Minimum demand charge with declining blocks

I - Minimum demand charge with increasing blocks

J - Flat charge

K - Flat charge varying by number of residents

L - All other forms

Table 4.

Summary statistics for rates structures, small cities

<u>Single block rates</u> (of all types)

per 1,000 gallons		Water		Sewer
High	Hanley Falls	$ 1.25	Wabasha	$ 1.10
Low	Sartell	.334	Elbow Lake	.05
Average		.645		.505
Median		.517		.45
Number of towns		10		9

<u>Flat charge</u> (of all types)

per month		Water		Sewer
High	Stacy	$ 7.00	Erskine	$ 7.00
Low	Marble	.50	7 towns	0
Average		3.18		2.49
Median		3.00		2.00
Number of towns		73		107

<u>Declining block rates</u> (of all types)

Price ratio of highest block to lowest block		Water		Sewer
High	Albertville	$ 18.00	Albertville	$ 18.00
Low	Steen	1.05	Pine City	1.03
Average		4.22		4.77
Median		3.49		3.33

Quantity at which lowest block begins (in gallons)		Water		Sewer
High	Lauderdale	3,740,000	Dawson	500,000
Low	Crosby	748	Crosby	748
Average		92,000		69,000
Median		25,500		30,000
Number of towns		134		61

Table 5.

Summary statistics for rate structures, medium-sized cities

<u>Single block rates</u> (of all types)

per 1,000 gallons		Water		Sewer
High	Windom	$ .67	Fairmont	$ .83
Low	Cottage Grove	.30	Roseau	.16
Average		.47		.49
Median		.44		.50
Number of towns		9		20

<u>Flat charge</u> (of all types)

per month		Water		Sewer
High	Hoyt Lakes	$ 6.00	Circle Pines	$ 7.00
Low	Babbitt	2.60	Wadena	.75
Average		4.57		3.36
Median		3.38		3.17
Number of towns		4		33

<u>Declining block rates</u> (of all types)

Price ratio of highest block to lowest block		Water		Sewer
High	Princeton	$10.00	Little Falls	$13.89
Low	St. Paul Park & Proctor	1.10	Lakeville & Stillwater	1.20
Average		2.22		3.18
Median		2.91		2.51

Quantity at which lowest block begins (in gallons)		Water		Sewer
High	Mendota Heights, West St. Paul, Falcon Heights, Northfield	3,740,000	Northfield	3,740,000
Low	New Hope	1,000	New Hope	1,000
Average		382,000		279,000
Median		100,000		100,000
Number of Towns		79		36

Table 6.

Summary statistics for rate structures, large cities

<u>Single block rates</u> (of all types) per 1,000 gallons		Water		Sewer
High	Bloomington	$ .66	St. Cloud	$ .64
Low	Crystal	.30	Richfield	.25
Average		.46		.42
Median		.38		.36
Number of towns		7		3

<u>Flat charge</u> (of all types) per month		Water		Sewer
High		-	Brooklyn Park	$ 4.50
Low		-	Moorhead	1.70
Average		-		3.03
Median		-		3.05
Number of towns		-		10

<u>Declining block rates</u> (of all types)

Price ratio of highest block to lowest block		Water		Sewer
High	St. Cloud	$ 7.69	Duluth	$ 10.10
Low	Winona	1.35	Winona	1.35
Average		2.86		3.25
Median		2.04		1.67

Quantity at which lowest block begins (in gallons)				
High	St. Cloud	29,922,000	St. Paul	7,480,000
Low	Rochester	30,000	Mankato	11,000
Average		4,919,000		1,878,000
Median		375,000		374,000
Number of Towns		11		5

Table 7.

Summary statistics for rate structures, all cities

<u>Single block rates</u> (of all types) per 1,000 gallons		Water		Sewer
High	Hanley Falls	$ 1.25	Wabasha	$ 1.10
Low	Crystal, Cottage Grove	.30	Elbow Lake	.05
Average		.535		.488
Median		.50		.475
Number of towns		26		32

<u>Flat charge</u> (of all types) per month		Water		Sewer
High	Stacy	$ 7.00	Erskine & Circle Pines	$ 7.00
Low	Marble	.50	7 towns	.00
Average		[illegible]		2.72
Median		3.00		2.50
Number of towns		77		150

<u>Declining block rates</u> (of all types)

Price ratio of highest block to lowest block		Water		Sewer
High	Albertville	$ 18.00	Albertville	$ 18.00
Low	Steen	1.05	Pine City	1.03
Average		3.45		4.13
Median		3.13		2.90

Quantity at which lowest block begins (in gallons)				
High	St. Cloud	29,922,000	St. Paul	7,480,000
Low	Crosby	748	Crosby	748
Average		431,000		232,000
Median		48,000		40,000
Number of Towns		224		102

Figure 8. FREQUENCY OF RATE FORMS (Water)

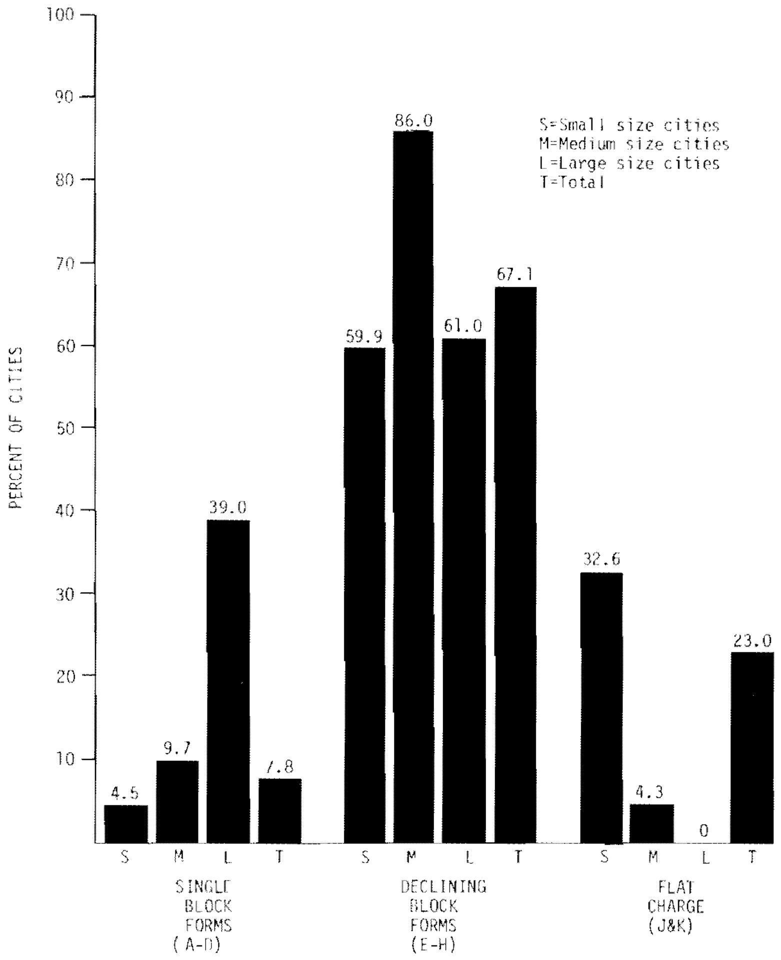
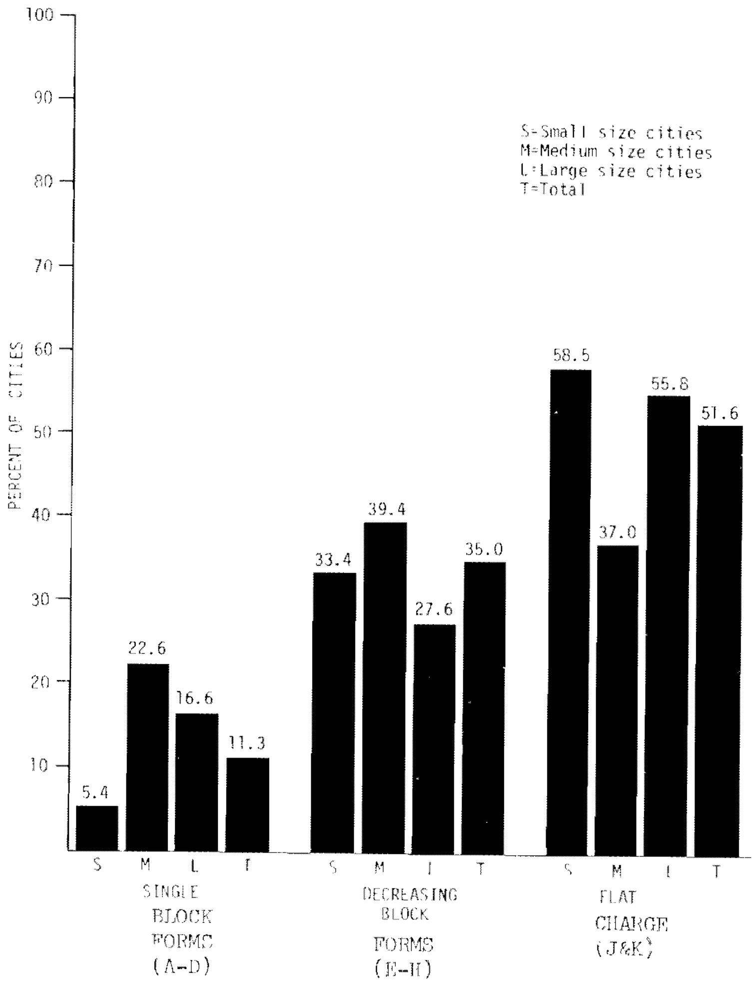


Figure 9. FREQUENCY OF RATE FORMS (Sewer)



$.42 to $.49 to $.505. This could reflect decreasing costs of larger systems due to economies of scale. Statewide, note that the average price for 1000 gallons of water or sewer service is very nearly the same with $.535 and $.488 respectively.

Monthly flat charges for water seem lower in the small towns, but the sample of medium-sized cities is very small. This trend seems more clear in sewer rates. Note that some small towns do not charge anything for their sewer service.

There are two discernible trends in the declining block rates for both water and sewer services. The price ratio of the highest to lowest block increases as city size decreases. This can be seen in the range of values in each city size, but this could be a function of the number in the sample. However, it is also evident in the median values. The large ratios occur when there is a minimum demand charge that inflates the per unit cost on the first block. Remember that these ratios can be justified economically only if the cost of pumping and delivering the water varies by the same ratio. It is doubtful whether economies of scale can reduce costs by a factor of three or more.

At the same time, the quantity at which the lowest priced block begins varies directly with city size. Since this quantity varies so widely, from 748 gallons to nearly 30 million, the median is the best statistic to use in comparisons. With either utility, this median quantity falls from about 375,000 gallons in large cities to around 30,000 in small cities.

The small towns using declining blocks tend to vary the price more and over a smaller quantity of consumption. Large towns tend to keep their declining blocks closer on the continuum to single blocks; they vary the price less and over a large range of quantity, where economies of scale may be working. On the basis of economic efficiency, large towns seem to have better rate structures than small cities. The heavier incidence of flat charges in small towns and single blocks in large towns is further evidence. This makes sense since large systems can afford to have specialists who are more aware of the issues in the pricing area.

To complete the analysis of Minnesota rate structures, monthly utility bills were calculated for each city for water and sewer. Consumption was held constant at 10,000 gallons a month to facilitate comparisons. This level is about what a family of four would consume at the mean consumption rate. Of course it is probably high for those cities with high prices. The resulting utility bills were compared by city size and by rate form as is shown in Tables 8 and 9.

Statewide, the average water bill at this level of consumption is $5.54, and the average monthly sewer bill is $4.79. The charges in large cities nearly match these levels. Small cities have lower utility bills, while medium sized cities charge more than the state average. The range for extreme values is largest in the small towns.

Table 8. Average Utility Bills at 10,000 Gallons per Month Consumption*.

		Water $		Sewer $
SMALL CITIES				
High	Madison	17.37	Grand Marais	14.02
Low	Marble	.50	7 cities	-0-
Average		5.23		3.47
Median		4.82		3.00
Number of cities		224		182
MEDIUM CITIES				
High	Chisholm	18.50	Granite Falls	9.63
Low	Babbit	2.60	Chisholm	-0-
Average		6.31		4.40
Median		5.90		4.33
Number of cities		92		91
LARGE CITIES				
High	Mankato	9.95	Mankato	7.80
Low	Rochester	2.41	Moorhead	1.70
Average		5.45		3.93
Median		5.54		3.58
Number of cities		18		18
STATEWIDE				
High	Madison	17.37	Grand Marais	14.02
Low	Marble	.50	8 cities	-0-
Average		5.54		4.79
Median		5.04		3.49
Number of Cities		334		291

* or 4 persons per residence are assumed where necessary

Table 9. Statewide Comparison of Utility Bills by Rate Form
(Average cost of 10,000 gallons per month or 4 persons per residence)

RATE FORM	WATER $	SEWER $
A	5.36	4.75
B	6.57	4.98
C	6.45	5.55
D	5.47	4.62
E	7.19	4.89
F	6.91	4.98
G	6.00	4.28
H	6.15	5.12
I	5.34	3.14
J	3.09	2.71
K	4.21	3.38
L	6.34	4.90
Average of all forms	5.54	3.79

Key for Rate Forms

A - Single block
B - Service charge plus single block
C - Single block with a minimum charge
D - Minimum demand charge with a single block
E - Declining blocks
F - Service charge plus declining blocks
G - Declining blocks with a minimum charge
H - Minimum demand charge with declining blocks
I - Minimum demand charge with increasing blocks
J - Flat charge
K - Flat charge varying by number of residents
L - All other forms

Comparing these average bills to the values in Table 9, one immediately notices how much lower are the bills from flat charges with $3.09 and $2.71 for water and sewer. In fact, when the flat charges are removed, the state average bill rises from $5.54 to $6.27 a month for water and from $3.79 to $4.97 for sewer service. If the water bills from proportional rate forms reflect costs, then the flat charge rate structures may be inadequate from a revenue raising perspective. Single block forms tend to charge residential customers slightly less, especially for water, while declining blocks have larger bills for small users.

Improving Rate Structures

There are some potential inequities in the rate structures now used in Minnesota. Most of these stem from the belief that price differentiation is a form of discrimination, with all the negative connotations.

The capital costs of a water distribution system is a major component of the cost of water. Additional funds are often spent to expand the water system into the outlying regions. Yet all customers are charged the same price for water. A price is charged which averaged all distribution costs. Those who live in the more densely populated city center subsidize the distribution costs of suburbanites.

The cost of water is therefore location-free. This is one small way of promoting the syndrome of expanding cities, decaying city centers, and decreasing agricultural land.

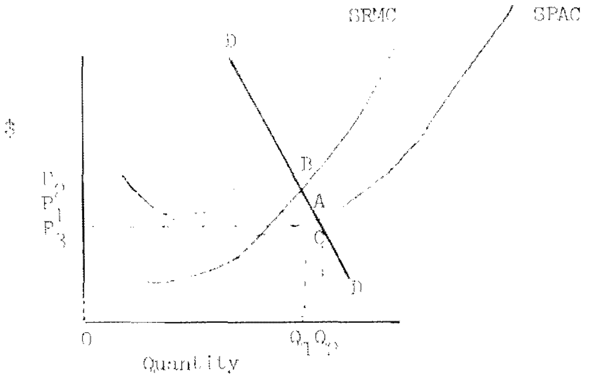
A similar subsidy occurs when the cost of water is averaged over the seasons. The demand for water is usually so much larger in the summer that extra capacity must be created for this season. The marginal cost of water in the summer is higher than in the winter. The result of a single rate structure is that inner city and apartment dweller share the cost of lawn sprinkling. Assuming that they do not enjoy the lawns of others, this is another inequity.

Average Cost vs. Marginal Cost Pricing

These are just two examples from a whole family of inequities. Similar situations exist with water quality differences among wells, time of water use, or the elevation from the water source. They stem from using average cost pricing policies instead of marginal cost. These inequities are good techniques of price discrimination if expansion of the system is a goal. Maximum economic efficiency only occurs when the price of water for each group of customers equals the marginal cost of getting water to them. If price exceeds marginal cost, then full economic utilization of the resource is prevented. If the price is lower than marginal cost, demand exceeds the optimum. This leads to premature and overly large investments in water systems. Benefits would be greater if the money were used elsewhere.

This can also be illustrated with the following graph in figure 10. The demand for water is assumed to intersect with the cost curves as shown. If the short-run marginal cost of P_2 is charged, the benefits of the last

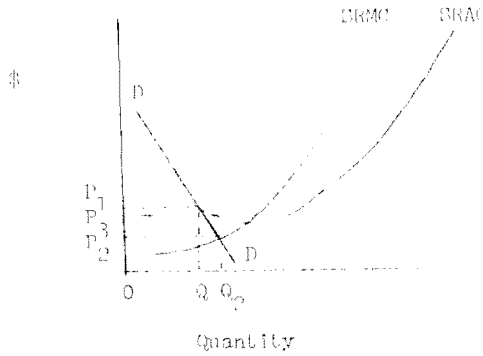
Figure 10. Relation of Demand, Cost, and Price of Water.



gallon of water just equals its costs. Static equilibrium in a system occurs when rising marginal costs meet the declining values of additional water use. Q_2 is produced. Total revenue is equal to the area within OP_2BQ_2. Costs are OP_3CQ_2, leaving a profit above costs of BCP_3P_2, which is equal to the difference between marginal cost and average cost multiplied by the number of units sold.

If price is made equal to average cost, then it will equal P_1, and Q_1 units of water will be sold. Revenue will just equal cost. However, for all those units beyond Q_2, the benefits of the water to the purchaser will be less than the marginal cost of producing those units. Again, that money would get a higher return to society for producing something besides water. Marginal cost pricing is clearly superior to average cost pricing in this situation.

Figure 11. Relation of Demand, Cost, and Price of Water.



A more difficult case for marginal cost pricing occurs in Figure 11. Here the demand curve intersects the cost curves where marginal cost is less than average cost. It is in a region of decreasing average costs. Now average cost pricing meets the revenue requirement and also results in less water sold. However, the benefits to the consumers of the units between Q_1 and Q_2 are larger than the cost of delivering the water, so those units should be sold on the grounds of economic efficiency. Marginal cost pricing would charge P_2 for Q_2 units of water. This would result in a net loss to the utility of the shaded area, the difference between MC and AC times the number of units sold. Marginal cost pricing could be kept on the grounds of economic efficiency if the needed additional revenue could be generated somehow.

There are several possible ways to do this. The most obvious is through a government subsidy. This is already done in many instances. The Metropolitan Water District of Southern California typically runs a huge loss on water sales and makes it up with a property tax levy.[1/] Sewer utilities must be doing this because in 1968 only 23% of total sewage disposal costs were covered by sewer user charges.

Another set of solutions involves capturing part of the consumer's surplus in order to make up the difference in revenue. In theory, this could be done through voluntary contributions. Each customer could contribute any amount that would leave him with excess benefits under the threat of loss of service. Practically speaking, this technique is unlikely to succeed due to the free rider problem. It is in the interest of each customer to refrain from contributing in hopes that the deficit will be covered by the gifts of others.

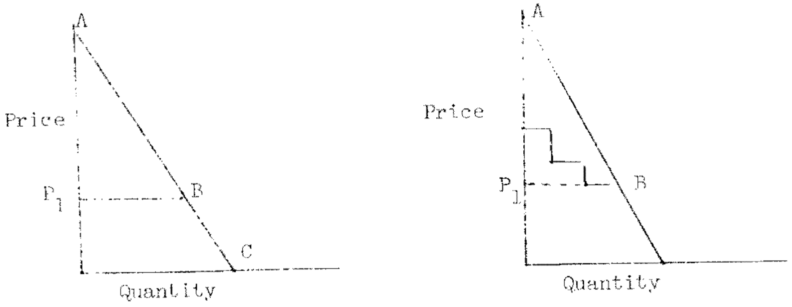
A better way of tapping consumers' surplus would be to set up a series of declining blocks for different customer groups with the stipulation that each group pay the same marginal price. A trial and error period would be needed to insure that all customers end up on the same equimarginal block.

Figure 12 illustrates this idea. The left graph shows that the triangle above the price paid and below the demand curve, AP_1B, is the consumers' surplus. People pay P_1 for all units, but were willing to pay more for all but the last unit. The right hand graph shows how declining blocks may take part of this consumer's surplus as revenue. There are some equity considerations here regarding what portion of consumers' surplus is removed from each group of customers. Incidentally, this inequity also occurs when large customers in a declining block structure must pay the higher rates for initial consumption.

A fourth way of recouping a revenue deficit is to assess a service charge. This charge should vary according to the intensity of demand by the different customer groups. It may create inequity and inefficiency if a purchaser of very small amounts decides the service charge is larger than his consumer's surplus and terminates his service. However, it is impossible to individually differentiate the service charge with equity.

[1/] Hirshleifer, Jack, James C. DeHaven, and Jerome Milliman, Water Supply: Economics, Technology, and Policy, Rand Corp., Santa Monica, Calif., 1960, p. 91.

Figure 12. Price and Demand for Water.



Finally the water system could engage in price discrimination to end a revenue deficit. This would be diverging from marginal cost pricing, but it is a common practice in water pricing today.

Cost Curves

What is the likely relationship of marginal cost and average cost? Is marginal cost greater than average cost as in the first case, or is it the opposite, in which case a deficit would be generated? The survey did not examine cost relationships, and no specific recommendations about rate levels can be made without them. A discussion of the likely shape of the cost curves does seem in order.

As a water system is expanded, it will have to use less and less advantageous sources of water supply. Of course, in an area like the Twin Cities there may be a large aquifer, such as the Jordan sandstone, which will provide huge amounts of water. Eventually, however, deeper aquifers will have to be tapped. In a case like California, water is transported from longer and longer distances. In any case, one would expect to see a general pattern of rising costs.

An expansion of capacity would cause an immediate rise in the short-run average costs. Average cost would then decline slowly as the extra capacity was absorbed by demand. The extent to which costs would decline would be constrained by the amount of capacity needed to accomodate peak demands. Economies of scale would be realized in the size of each expansion. Larger expansions would cause a higher initial increase in average cost followed by a larger decline over a larger quantity of water produced. It is likely that water could be produced beyond the "capacity" of any system by a finite increase in average cost.

The resulting envelope of short-run average cost curves is shown in Figure 13. Note the position of short-run marginal cost relative to average cost depends on how much excess capacity exists at any time. If a water system has been recently expanded, average cost will be decreasing, marginal cost will be below it, and a deficit in revenue will occur.

But if a system is delaying expansion and is at maximum production, marginal cost will exceed average cost. It is not possible to state generally whether marginal cost pricing will produce a surplus or deficit. If implemented precisely, this method will mean that price will fluctuate over time.

Figure 13. Short Run and Long Run Marginal Costs of Water Supply.

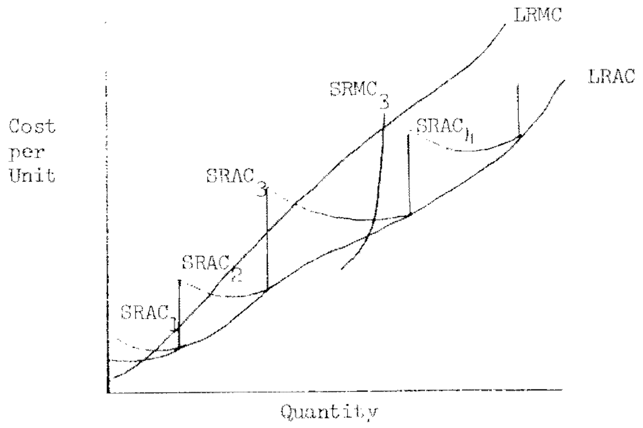


Figure 13 also shows the long-run cost curves. The author feels that marginal cost pricing should reflect short-run marginal costs since most water contracts are for short periods, and price can be altered.

Peak Load Pricing

The demand for water is not constant. Each class of users has its potential peak demands which are based on the number and size of connections to the system. These peaks are more or less predictable and may or may not coincide with the peak demands of other classes.

The water system must have extra capacity to accomodate these higher water demands. If marginal cost pricing was in ideal operation, there would be no problem. The price of water would simply increase at the times of peak demands as marginal cost increased. However, at present it is not feasible to install the metering equipment necessary to monitor individual consumption rates over such short time periods.[1]

The next best alternative is to install a system of capacity or service charges.[2] This would be a fixed charge based on the cost of the amount of extra capacity that the system must provide for each class.

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[1] Hirshleifer, et al., op. cit., p. 105.

[2] Hirshleifer, et al., op. cit., p. 102.

It could be construed as a charge for each customer's option-to-buy, the open-ended contract to purchase any amount of water at any time. The collective demands of residential users for such uses as air conditioning and sprinkling are likely to outweigh industrial peaks, and so they would bear the majority of the capacity costs.[1] Identifying those residents with these special uses and putting them in a separate class would provide even more equity. It should be noted that the cost of the peak demands often comes in the form of decreased quality of service, namely loss of water pressure.[2]

For sustained seasonal peaks that occur in the summer in most areas, a system of peak-load pricing is possible. The marginal cost of producing the extra water should be the peak price charged. This would have the desirable effects of reducing these peaks through the price elasticity. Expansions of the system could then be delayed. A study by Hanke and Davis (20) found that seasonal pricing could delay water investments in Washington, D.C. for ten years.

The height of the summer peaks could also be reduced by public education programs to sprinkle lawns during off-daily-peak hours. This would lower the amount of capacity needed for peaks.

A Proposed Rate Structure

At this point a modified marginal cost rate form will be presented. It will not generate optimal efficiency in resource allocation due to some feasibility constraints and at least one subjective decision. This rate form should, however, correct many of the problems of present Minnesota pricing practices.

The rate form will have a two-part tariff consisting of a service charge and a single block commodity charge for each class of customers. The service charge will reflect the contribution of that class towards demand peaks. The single block will reflect the marginal cost of providing a unit of water to member of each category. A step-by-step hypothetical example of this rate form follows the explanation and should help illustrate the method. The rates should be computed in this manner.

1. Find the average daily winter water consumption. This is the base capacity that would be needed if demand were perfectly constant. Calculate the <u>replacement</u> cost of this base capacity, which is the cost of providing the production facilities and keeping them ready to serve. Divide this cost by the average consumption to get the base per unit capacity costs.

2. Find the average daily summer water consumption and subtract from it the winter daily average. In Washington, D.C. summer use is 24% higher than winter use.[3] Calculate the marginal replacement cost of this added capacity. Assess the proportion of this peak created by each demand sector. Divide the cost by the amount of additional water used by each sector to arrive at the peak season addition to capacity cost.

3. Find the peak hourly rate of consumption. Subtract from it the average peak season daily consumption converted to an hourly basis. This is the additional capacity that must be maintained for peak demands during any day. Calculate its marginal replacement cost. Determine how much of the peak is caused by each demand sector. Divide this proportion of the peak capacity cost by the number of customers in each demand sector. By assessing this cost, a revenue deficit should be avoided.

4. Find the customer costs of monitoring consumption, keeping accounts, and billing each demand sector. Divide these costs by the number of customers in that section. Add this figure to the peak capacity cost per customer for each demand sector to obtain the service charge for each sector.

5. Find the marginal commodity cost at the base capacity rate. This includes the cost of pumping the water out of the well, the chemicals added, and any other variable costs.

6. Since all pumps have an optimum rate of operation, and surface water quality may change during the year, calculate the marginal commodity cost at the peak rate.

7. Calculate the distribution costs of getting the base capacity water to the various customer groups. Here the usual demand sector of industrial, commercial, and residential customers may have to be subdivided for equity. Breaking down the residential sector into central and outlying areas seems especially important, but other divisions may be made depending on the individual system.

   These costs are often called fixed and as such should be divided by the number of customers and put into the service charge. The cost of pumping the water through the distribution system is, of course, variable. But to the extent that raising consumption does not affect the distribution system, the capital and maintenance costs are fixed - they would have to be paid regardless of how much water was pumped.

   However, with water systems, one-half to two-thirds of all costs are fixed.[1] If these fixed costs were all placed in the service charge, the majority of water costs would be independent of water use. The resulting commodity charge would be too low to have much effect on consumption decisions. The AWWA was disturbed by this and decided that capital costs are as much a part of production costs as anything else. They suggested that "theory should not be carried to extremes and that consumption charges should, in

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[1] Hirshleifer, et al., op. cit., p. 103.

[2] Ibid, p. 105.

[3] Hanke, S.H., "Water Rates: An Assessment of Current Issues," <u>Journal of American Waterworks Association</u>, Vol. 67, No. 5, May 1975, pp. 215-219.

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[1] "Determination of Water Rates Schedules", <u>Journal of American Waterworks Association</u>, XLIV, March, 1954, pp. 187-219.

all cases, carry the major part of the cost of service". They then allocated 50% of capital costs to the service charge and 50% to the commodity charge. This is not very satisfactory from an efficiency standpoint either.

The size and cost of the distribution system may indeed change with the amount of consumption as larger mains are needed. Another defense is that the large users will be using the distribution system more. In any case, base distribution costs should be divided by the base consumption of each group. Residential areas will have the highest costs here as water must be delivered to each housing unit.

8. To the extent that the distribution systems had to be enlarged to accomodate peak season and daily peak water usage, marginal distribution costs should be figured.

9. The service charge has already been found by adding customer costs and peak demand capacity cost for each customer group. Now adding the base per unit capacity cost, the base per unit commodity cost, and the base per unit distribution cost, the winter commodity charge for each class is determined.

10. Adding the peak season per unit capacity cost, the peak season per unit commodity cost, and the peak season per unit distribution cost, the peak season commodity charge for each class emerges.

11. Each individual customer should pay the one-time cost of hooking up to the water system, adding the metering equipment, and listing the new account.

Example of Modified Marginal Cost Pricing

This example is completely hypothetical; the resulting prices may not be representative. Assume a small water system will a population served of approximately 2,000. The first residential area (Res_1) is the city proper; the second (Res_2) is an outlying subdivision that was recently annexed.

	Service Connections	Consumption Ave. Daily Winter
$Residential_1$	400	66,700 gal.
$Residential_2$	200	33,300 gal.
Institutional	15	25,000 gal.
Commercial	50	50,000 gal.
Industrial	10	75,000 gal.
	675	250,000 gal. or 10,400 gal./hr.

The peak demands cited by Hirshliefer, et al. (23) as the average of 206 cities. Peak monthly consumption (140% of average) 350,000 gal./day or 14,600 gal./hr.

80% of peak due to Res_1 and Res_2, 10% Inst and Comm, 10% Ind

Peak hourly consumption (267% of average) 27,800 gal./hr.

7% compound interest loans are assumed for all investments

1. Base capacity cost = $.24/1000 gal.

Replacement cost of pumping and filtration plants and land $100,000
Paid over 50 years at 7% $7,250

Well, well column, gearhead, pump, maintenance equipment $ 50,000
Paid over 20 years at 7% $4,700

Labor $10,000

$21,950

$21,950/(250,000 gal. x 365 days) = $.24/1000

2. Peak season addition to capacity cost = $.039/1000 gal. Res_1 and Res_2
$.005/1000 gal. Inst., Comm, Ind.

Marginal replacement cost of providing extra 4,200 gal/hr. capacity $5,000

Paid over 20 years at 7% $472

If peak season last four months

.8 x $472/(80,000 gal. x 122 days) = $.039/1000 gal.

$47.2/(10,000 gal. x 122 days) = $.005/1000 gal.

3. Charge for peak capacity: $.35/month Res_1 and Res_2
$.64/month Comm, Inst
$2.75/month Ind

27,800 - 14,600 = 13,200 gal/hr. peak capacity needed

Replacement cost: $35,000 over 20 years at 7% $3,304

75% due to Res_1 and Res_2 $2,478/600 connections/12 months = $.35/month

15% due to Comm and Inst $496/65/12 = $.64/month

10% due to Ind $330/10/12 = $2.75/month

4. Customer costs of metering consumption, billing, and maintaining accounts

Res $.65/month

Comm, Inst $.75/month

Ind $1.00/month

5. Commodity costs of producing potable water during winter

   $.01/1000 gallons in winter

6. Commodity costs of producing potable water during peak season

   $.09/1000 gallons (increase due to higher, less efficient pumping rates and increased pumping to storage tanks)

7. Distribution Costs Res$_1$: $.587/1000 gal. Res$_2$: $.784/1000 gal.

   Inst, Comm: $.174/1000 gal. Ind: $.116/1000 gal.

   Replacement Cost of distribution system including mains, hydrants, storage tank, and maintenance equipment: $300,000 over 50 years at 7% $21,750

   Maintenance labor and power transmission: $10,000

   45% due to Res$_1$, $14,288/(66,700 gal x 365 days) = $.587/1000 gal.

   30% due to Res$_2$, $9,525/(33,300 gal. x 365 days) = $.784/1000 gal.

   15% due to Comm and Inst, $4762/(75,000 gal x 365 days) - $.174/1000 gal.

   10% due to Ind, $3,175/(75,000 gal. x 365 days) = $.116/1000 gal.

8. Assume that the minimum size distribution system could handle peak demands.

9. Service charges: Res$_1$ and Res$_2$ $.35 + $.65 = $1.00/month
   Inst and Comm $.64 + $.75 = $1.39/month
   Ind $1.00 + $2.75 = $3.75/month

   Base (winter) commodity charge:

   Res$_1$: $.24 + $.08 + $.587 = $.907/100 gal.

   Res$_2$: $.24 + $.08 + $.784 = $1.104/1000 gal.

   Inst, Comm: $.24 + $.08 + $.174 = $.494/1000 gal.

   Ind: $.24 + $.08 + $.116 = $.436/1000 gal.

10. Peak season (summer) commodity charge:

    Res$_1$: $.24 + $.039 + $.09 + $.587 = $.956/1000 gal.

    Res$_2$: $.24 + $.039 + $.09 + $.784 = $1.153/1000 gal.

    Inst, Comm: $.24 + $.005 + $.09 + $.174 = $.509/1000 gal.

    Ind: $.24 + $.005 + $.09 + $.116 = $.451/1000 gal.

11. Hook-up charge, including meter and accounting: $50.00

Private vs. Societal Perspectives

One final idea to keep in mind is that private benefits and costs may diverge from benefits and costs to society in water use. A good example is the effects of irrigating a lawn. If the lawn is fenced in, it is enjoyed only by the owner, and by rights, he should pay the entire cost of the water used to keep it green. But when the green lawn is enjoyed by passersby, the situation differs. Societal benefits now are greater than private benefits. A town may decide to subsidize lawn irrigation in order to maintain the aesthetic assets of the community.

On the other hand, private costs may be lower than social costs. A common instance of this occurs with agricultural irrigation. A farmer need only pay for a well and irrigation rig to water his fields. However, he is using precious groundwater for this purpose. The rate of use in that area may or may not exceed the rate of groundwater recharge. If it does, a limited stock resource is being depleted. The value of this water to society would likely be greater than the farmer's pumping costs. Currently, information about groundwater supplies in Minnesota is very sketchy. There is some justification for a groundwater user charge that will be more apparent after a groundwater inventory has been made.

Such differences between private and social benefits and costs need to be examined more closely. Comparing the invaluable functions that water serves and, oftentimes, the lack of substitutes for it, to the prices paid for it, the price of water seems low. However, there may be some uses of water that are in the public interest to continue.

CONCLUSIONS AND RECOMMENDATIONS

1. The size of the population served by the water system, the proportion of children under eighteen years old in the community, the marginal price of water and sewer in the winter, and per capita income significantly help to explain differences in per capita daily residential water consumption in mid-sized Minnesota cities. Much of these differences, however, is left unexplained. It is thought that a better climatic variable and a measure of per capita lawn area might improve the explaining power of the model.

2. Price does not play an important role in determining absolute levels of residential water use. Other factors such as the number of children and income seem to be more important. Water prices appear to be too low to place much of a constraint on water consumption. The rather inelastic income elasticity of .36 supports the idea that many people have already satisfied their water needs. Expenditures for water will not rise proportionately with income.

3. The price of water does have a significant relative effect for reducing water consumption. Price elasticies in the range of -.15 to -.24 were found for residential water consumption in Minnesota. If anything, these estimates are biased in a downward direction. Increases in the price of water will have a negative effect on water consumption. The results of the study do not contradict the theoretical idea that consumers react to the marginal price of water and sewer in the winter, that is, the amount their utility bills are reduced by the consumption of one less unit of water.

4. As price is increased,the price elasticity of demand will rise also. The arc elasticity experiment supports this. This means that price increases are likely to have a larger conservation effect than the elasticity estimates of this study indicate. This is consistent with moving upward from a rather low point on a linear portion of the residential water demand curve. Consumption will rise proportionately less when the price of water is lowered.

5. Increases in water prices will raise the revenues of public utilities. This may be especially important for sewer systems, which often operate at a loss.

6. There are several ways in which the rate structures for Minnesota water and sewer utilities might be changed. These alterations should improve the economic efficiency and the equity to all customers. These recommendations may not apply to every city in Minnesota, and specific guidelines for rate levels cannot be made without further information about costs. They are, however, important directions for change.

   A. Rate structures for both water and sewer service should be changed to ones which reflect the marginal costs of service. Marginal cost pricing reflects the philosophy that those who benefit from a product should pay its entire cost. One such rate form was suggested in this study.

   B. It is important to install a seasonal price system. This would typically be a two-price system that charged more for water during the peak summer season. This is a more equitable and efficient way of dealing with the higher costs of providing water for lawn irrigation. One indirect way to do this would be to allow sewer costs to vary with water consumption all year instead of just in the winter. However, the additional revenue would then go to the sewer utility.

   C. As a corollary to the preceding recommendation, a concerted public education program to switch lawn sprinkling to the off peak evening hours would be beneficial. It would help avoid water pressure losses and would delay the expansion of water systems.

   D. Those systems with meters that have flat rate structures for water or sewer should change to a rate structure which levies charges proportional to water use, preferably marginal cost pricing. Those systems using flat rates that have no individual meters should strongly consider installing them. Since meter installation has been shown to reduce consumption, it is nearly imperative to install meters before expanding the water system further. If meters cannot be used, a switch to a flat rate system varying with the number of residents or number of plumbing fixtures is recommended.

   E. In general, declining block rates should not vary the price as much as many presently do, unless costs can be shown to vary in the same ratio. Otherwise, waste of scarce water is promoted at a net loss to the water utility. Also those structures which contain many blocks that change over a small quantity should be simplified. There is no apparent economic justification for numerous steps.

   F. Minimum demand charges and minimum charges should be dropped in favor of a service charge. Minimum demand charges can serve to encourage water consumption and disguise the true cost of purchasing additional water. The service charge makes the difference explicit.

   G. A single, separate charge should be made for hooking up to the water system equal to the marginal cost of these services. Hook-up costs should not be covered by the rate structure.

7. The relatively low estimates of price elasticity of demand do not mean that the requirements philosophy has been upheld. Residential demand should be the most inelastic since it includes those uses necessary for human survival. Its elasticity was shown to be different from zero, which in itself contradicts the requirements theory.

However, power plants, agriculture and industry account for far more water use. Since they receive a tangible value-added from their water use, these sectors should have a greater economic incentive to switch to water saving technologies as the price of water rises. They have more potential for substituting capital and labor inputs for water. In other words, the price elasticity for these other uses should be higher than the estimates for residential water demand. The requirements method should provide even less accurate forecasts of water demand for these uses. Future demand forecasts should use a method which accounts for possible price variation.

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APPENDIX

UNIVERSITY OF MINNESOTA
TWIN CITIES

Department of Agricultural and Applied Economics
231 Classroom Office Building
St. Paul, Minnesota 55108

Dear Water Manager:

We are conducting a study of residential water use in Minnesota. Included is an attempt to systematically gather data on water and sewer charges for municipalities in Minnesota. In addition, we intend to conduct a statistical analysis of water use in response to price of residential water and other factors. In this way, we hope to explain factors which influence residential water consumption in Minnesota.

We hope that the information derived from this study will be helpful to water utilities in planning future operations. The results of the study will be made available to interested parties.

It would help us to conduct the study if you would be so kind as to answer the enclosed questions to the extent that you have the information available.

If you have any questions on the questionnaire, please contact:

Mr. Richard L. Gardner
University of Minnesota
Department of Agricultural and Applied Economics
231 Classroom Office Building
St. Paul, Minnesota 55108
Telephone: (612)373-1093

A return envelope is enclosed for your convenience.

Thank you for your consideration in the matter.

Sincerely,

Paul B Johnson
Paul Johnson, Chief
Section of Public Water Supply
Minnesota Department of Health

Richard L. Gardner
Richard L. Gardner
Research Assistant

John J Waelti
John J. Waelti
Professor

Enclosure

WATER USE SURVEY

MUNICIPALITY ____________

1. Here are the figures for your average daily water consumption and number of service connections. Can you update them?

1973 daily water consumption ____________ 1973 service connection ____________

Present daily water consumption ____________ Present service connection ____________

2. Since we are concerned with household water consumption, it is essential that we know the amount of water that is used for each sector. If these figures are not available, please estimate them and identify them as estimates. Also please state the time period (daily, monthly, quarterly, annual) of your consumption figures.

	Number of Service Connections	Quantity in Gallons
Residential	________	________
Institutional (schools, churches, etc.)	________	________
Commercial (offices, restaurants, etc.)	________	________
Industrial	________	________
TOTAL	________	________

3. What are your present water rates? (Indicate for all classes, if different).

4. Have you changed these rates in the last five years? __________
If so, please describe the previous rates and the date of the change.

5. What are your present sewer rates? (Indicate for all classes, if different).

6. Have you changed these rates in the last five years? __________
If so, please describe the previous rates and the date of the change.

7. What sorts of treatment does your water receive before delivery?

8. What are your annual costs of operation? (If your cost figures do not fit the categories given, feel free to combine or change the breakdown).

Distribution costs (water main maintenance, auxiliary pumping, etc.).

____

Production costs (pumping, chemicals, maintenance).

____

Depreciation

____

Administrative

____

9. What is your gross annual income from water sales?

10. Would you like a copy of the conclusions of this study? __________

11. Name ____________________________________

Title ____________________________________

Address (if different from the one used) ____________________

____

____

Telephone ____________________________________