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Factors Affecting Residential Water Demand In and Around the Big Sioux River Basin

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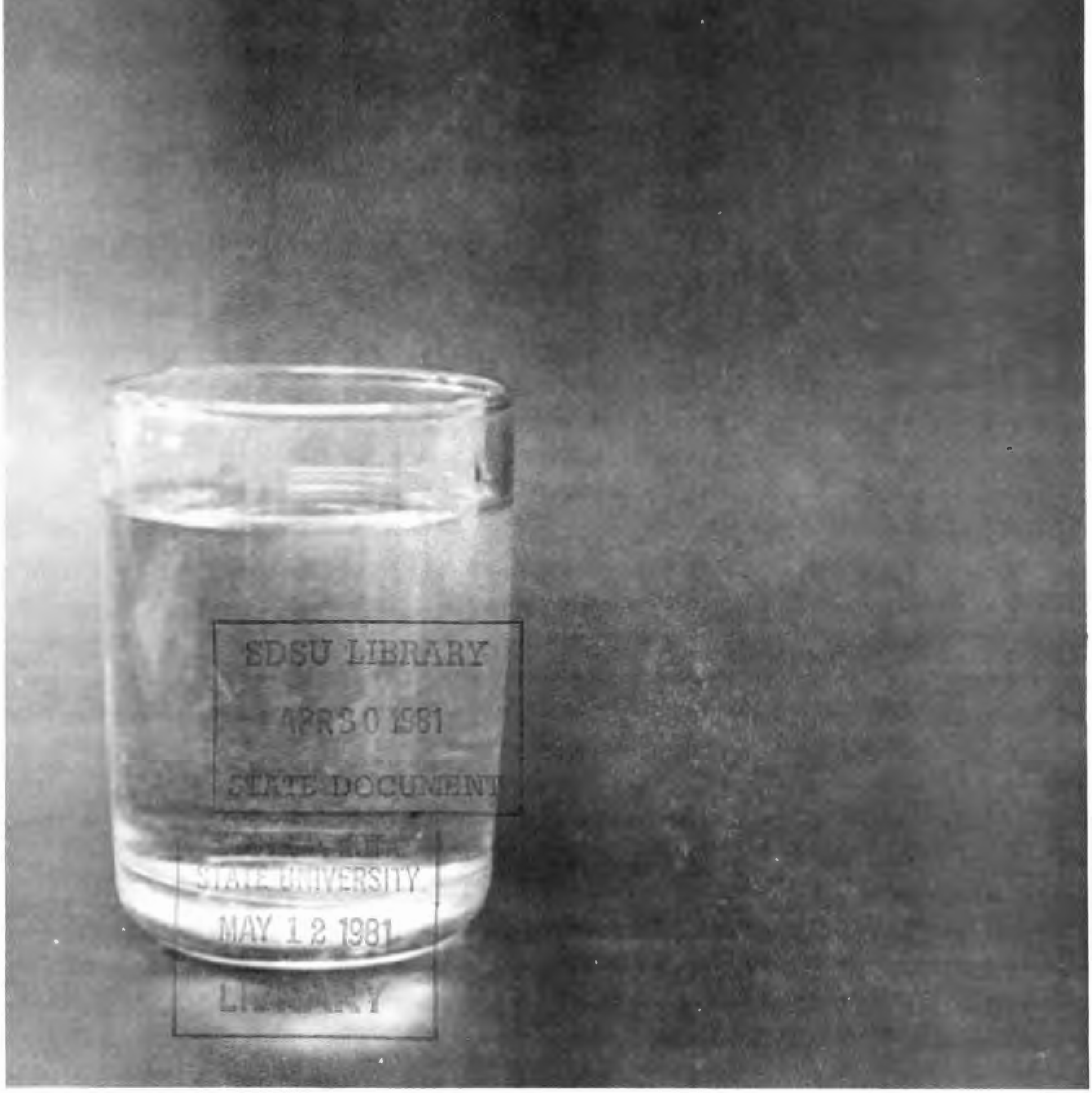

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Factors Affecting Residential Water Demand

In and Around the Big Sioux River Basin

Jeffrey Platek and Ardelle Lundeen*

An adequate supply of usable water has determined the location and growth potential of many communities. When supply is abundant, the cost of providing water to residents is low. With depletion of easily accessible supplies, providing additional water becomes increasingly expensive.

Nevertheless, as the population of a community grows, a common solution has been simply to expand water supply to meet growing demand irrespective of cost. Little effort has been made to hold down consumption in accordance with available supply.

With the growing realization that the amount of available water is not infinite, the practice of continually increasing supply to meet demand is being closely examined. Developing new water sources and constructing new and/or larger reservoirs or purification plants to expand the supply of water may be economically and technically infeasible.

An alternative approach to a water shortage would be an enactment of policies to reduce the amount of water consumed. Recent regional studies have indicated that the quantity of residential water demanded is responsive to changes in price, and that the demand for water may be affected by changes in income, population, or climate.

A demand function for water for a region should include variables which affect water consumption and the degree to which such consumption is affected. Water utility managers may be able to alleviate future water shortages with policies designed to reduce the demand for water.

As a tool for managers of public water systems, price is of prime importance since it is the one variable that can be easily changed. A regional demand function for water will indicate whether price can be utilized as a policy tool to achieve the desired change in quantity of water demanded within that region.

Objectives of Study

The objectives of this study were to: (1) Estimate demand functions for residential water use; (2) Identify variables which affect residential water consumption; and (3) Estimate price and income elasticities for water consumption.

Previous Research

Prior studies have dealt with rural residential demand, large temporary increases in price, water demand in central city and surrounding suburbs, demand in different regions across the nation, and in entire states.

Gruenwald (1975) developed a model for a rural Kentucky region in which the quantity of water demanded in thousand gallons per dwelling unit was a function of price, income, value of residence, evaporation rate, and number of residents per dwelling unit. A non-linear model had a R^2 of .67 compared to .15 for a linear model. Price elasticity was -.92.

Wong (1972) observed the effect of price, income and average temperature

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on the demand for residential water in Chicago and 59 suburbs. He found that price was not a significant variable for Chicago but was for its surrounding communities. Price elasticity was -.52 for Chicago and ranged from -.81 to -.20 for the smaller size communities. Income was significant for only the two largest communities.

Grima (1972) conducted a water demand study based on thirty-two municipalities in and around Toronto, Canada. He developed six variations of a model with three dependent variables: residential water use in gallons per day per dwelling averaged over the year, over the summer months, and over the winter period. These dependent variables were used with two sample groups: single-unit residences and groups of townhouses. For townhouses, non-linear forms of the model had a higher R^2 and resulted in price elasticity from -.75 to -1.07. Price, number of persons per household, and value of residence were significant variables.

The Howe and Linaweaver (1967) demand study was unique in that it dealt with water demand in regions throughout the nation. The primary objective of the work was to observe the effect of price on the quantity of water demanded for residential use in two areas: indoor (domestic) and outdoor (primarily sprinkling).

Data were obtained from 39 study areas ranging in size from 16 dwelling units to 2373 dwelling units over a time span from October 1961 through June of 1966. The 39 areas represented five climatic conditions or types of water service found within the continental United States. Howe and Linaweaver found generally that price elasticity for sprinkling demand for the eastern United States was higher at -1.6 than for the dryer western areas where price was -.7. For residential use, demand was rather inelastic with a price elasticity of -.23. Income elasticity was approximately .35.

Four separate studies undertaken by Berry and Bonem (1974), Turnovsky (1967), Gardner (1977), and Dall and Chen (1975) dealt with residential water demand on a statewide basis. Price was a significant variable in only two of these studies and in all studies price elasticity was very low, ranging from -.14 to -.47.

This diversity in type of study is reflected in the objectives, methods, and conclusions of each. Nevertheless, certain variables were common to all of the studies reviewed. Of the many variables tested for significance of effect on water demand, the following were common to all studies.

1. The price of water.
2. Household income or a proxy. (Value of residence was used in some studies.)
3. The number of persons per dwelling unit or population.
4. A climatic variable.

This current study differs from most previous studies because it combines cross-sectional and time series data by using monthly residential water use demand in eight South Dakota cities over a six year period. Other studies have examined total water consumption in several locations for one period of time or consumption in one location over a period of years.

PROCEDURE

Demand for Water

There are conceivably as many distinct demand curves[1] as there are distinct uses for residential water. For example, water used for strictly domestic purposes such as washing, cooking, and personal hygiene is expected to have a steeply sloped or inelastic curve. This curve is represented by d_1 in Figure 1 (a). Since water use in this case is for the most part necessary for normal household and health

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[1]A demand curve illustrates the various quantities per unit of time of a good that a buyer is willing to buy at all alternative prices, other things being equal.

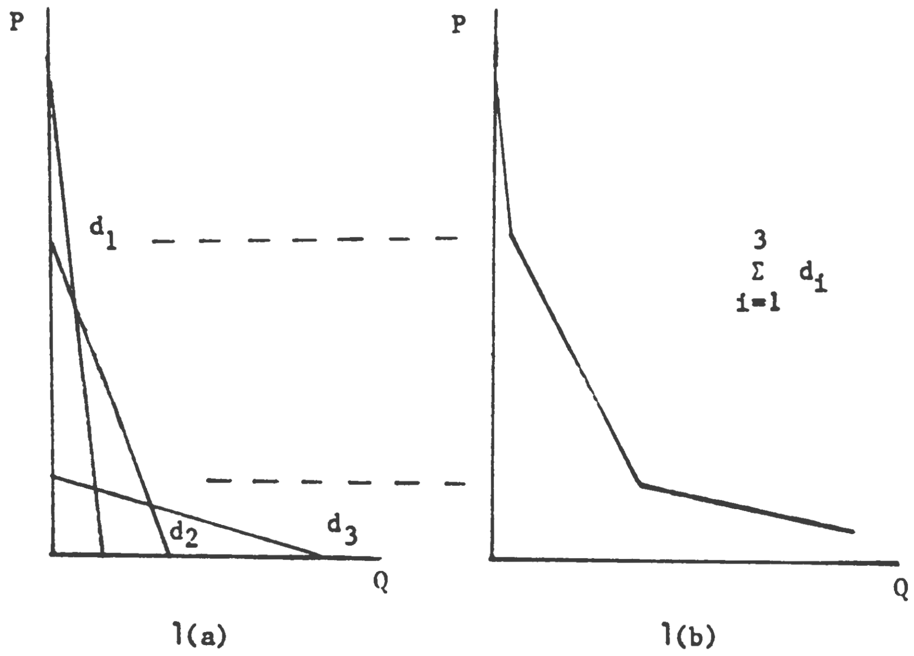

Figure 1. Demand for Residential Water (Adopted from Grima, 1972, p. 93)

maintenance, an increase in the price of residential water will not prompt a large decrease in the quantity demanded.

Water use of lesser importance should be associated with a less steep demand curve, reflecting a higher price elasticity.[2] This curve is represented by d_2. Water use in this case would be for such purposes as lawn watering, garden care, and car washing.

The least steep curve, d_3, represents the least important water consumed by households such as water lost through neglected leakages.

When many of these 'curves' are added horizontally to represent a household's total residential water demand, a segmented demand curve is obtained, as shown in Figure 1(b). Gardner (1977, p. 4) states:

"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 in varying utility, the demand function may approach the shape of a smooth curve."

The implication of such a demand curve for policy makers is that when water is used only for necessities, increases in price would not encourage large decreases in the quantity of water demanded. However, for non-essentials, water use should be highly responsive to changes in price, if price is a significant determinant of quantity demanded and not nominal for all users.

The demand for water by a household may be affected by many factors other than price, however. One of the objectives of this study was to ascertain which variables were most significant in affecting

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[2]Price elasticity of demand measures the responsiveness of quantity demanded to changes in price. It is computed as the percentage change in quantity demanded divided by the percentage change in price. Demand is said to be elastic if the absolute value of the elasticity coefficient is greater than one, inelastic if less than one, unitary if equal to one.

residential water demand. The knowledge of which variables in previous studies showed some consistency in their significance or insignificance was beneficial in selecting the independent variables which were used in this study. A second factor in the selection of variables was simply the availability of data.

Theoretical Model

Previous research indicated that monthly residential water consumption varies according to the season of year. Therefore, models were developed to estimate average monthly household water consumption in both the spring and summer quarters. The theoretical model for the summer quarter was:

$$Qd_{it} = f(P_{it}, N_{it}, YCAP_{it}, C_{it}, U_{it}) \qquad (1)$$

where Qd_{it} = the average monthly quantity of water demanded per household in cubic feet, in community i, in period t;

P_{it} = the price in dollars (deflated to 1967 constant dollars) of the first 1000 cubic feet, in community i, in period t;

N_{it} = the average number of persons per household in community i, period t;

$YCAP_{it}$ = the average annual income per capita (deflated to 1967 constant dollars) in community i, in period t;

C_{it} = the average monthly rainfall deficiency in inches, in community i, in period t; and

U_{it} = random error.

A variation of this model was:

$$Qd_{it} = f(MC_{it}, N_{it}, YCAP_{it}, C_{it}, U_{it}), \qquad (2)$$

where MC was substituted for P in the first model (1) and where

MC_{it} = the first marginal price[3] of residential water (deflated to 1967 constant dollars), in community i, in period t.

An additional variable, C', was incorporated and substituted for the variable C in several equations, where:

C'_{it} = the average monthly rainfall in inches in community i, during period t.

The climatic variable was omitted in the spring quarter equations. The reasoning for this and the use of C' are explained later.

Both linear and curvilinear functions were examined to determine which curve would produce the best fit.

The theoretical curvilinear model in multiplicative form is:

$$Qd_{it} = a \cdot P^{b}_{it} \cdot N^{d}_{it} \cdot YCAP^{e}_{it} \cdot C'^{f}_{t} \cdot U^{g}_{it} \cdot$$

It was converted to the logarithmic form and fitted by use of least squares multiple regression. When the logarithmic transformation was used, the model for equation (1) became

$$\text{Log } Qd_{it} = \text{Log } a + b \text{ Log } P_{it} + d \text{ Log } N_{it} + e \text{ Log } YCAP_{it} + f \text{ Log } C'_{it} + g\, U_{it}, \qquad (3)$$

and for equation (2)

$$\text{Log } Qd_{it} = \text{Log } a + c \text{ Log } MC_{it} + d \text{ Log } N_{it} + e \text{ Log } YCAP_{it} + f \text{ Log } C'_{it} + g\, U_{it}. \qquad (4)$$

With the logarithmic form, the elasticities of demand for the different variables are the coefficients (b, c, d, e, f). The climatic variable was omitted in the spring quarter curvilinear model.

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[3]the price for the first 100 cubic feet used after the minimum change. See pages 8-9 for a further explanation of this variable.

Variables in Model

There is a growing awareness of the need for residential water demand studies, but research in this area is often difficult because of the numerous problems encountered in design, data collection, and analysis. Wong (1972, p. 35-36) discusses four problem areas which are prevalent in water demand studies. These are:

(1) Water consumption data are generally at best, "guesstimates". Billing periods vary from month to month, and often municipal water consumptions data fail to separate the quantities of water demanded by the residential, commercial, and industrial sectors of the community;

(2) There is no uniform pricing policy for residential water;

(3) Income data are often difficult to obtain, and thus proxy variables are necessary; and

(4) Sample reliability is often questionable. In time-series analysis, the period may be too short (e.g., give five or fewer years for a series), while with cross-sectional analysis, the sample may be too small (e.g., six or seven observations as a sample for a state).

Each of the problems stated above was encountered to some degree in the data collection process for this study. Due to a general lack of data for many of the smaller communities (population less than 5,000) within the Big Sioux River Basin, the data base was limited to eight communities within or adjacent to the study region[4] and covered a six-year period from 1972 through 1977.

These communities were selected primarily on the basis of population, the use of a metered water system, and/or data availability. Five communities within the Big Sioux River Basin (Brookings, Madison, Sioux Falls, Watertown, and Webster) met these requirements.

To increase the sample size, Aberdeen, Huron, and Yankton were also included. These latter communities which met the specified requirements were located near the Big Sioux River Basin and displayed geographic, topographical, and climatic characteristics similar to those of communities within the Basin. Residential water consumption, rate structure, and water use restriction policy data for the spring and summer months of each year were obtained from the water utility departments of each community.

By deflating price and income data to 1967 dollars, time-series and cross-sectional data were combined in the regression analysis. Using this procedure forty-eight observations were available rather than six for a time-series study or eight for a cross-sectional study.

Average Monthly Household Water Consumption:

Consumption is the dependent variable regressed on selected independent variables. Records in several communities contained aggregate monthly residential, commercial, and industrial consumption.

To isolate residential consumption, samplings of commercial and industrial water consumption were taken. Based on these samples, estimates of commercial and industrial water consumption were subtracted from the total municipal consumption figures to estimate the quantity of water consumed by the residential sector. In each community, the resulting estimate of residential water consumption was divided by the number of residential customers to derive an estimate of average monthly household water consumption.

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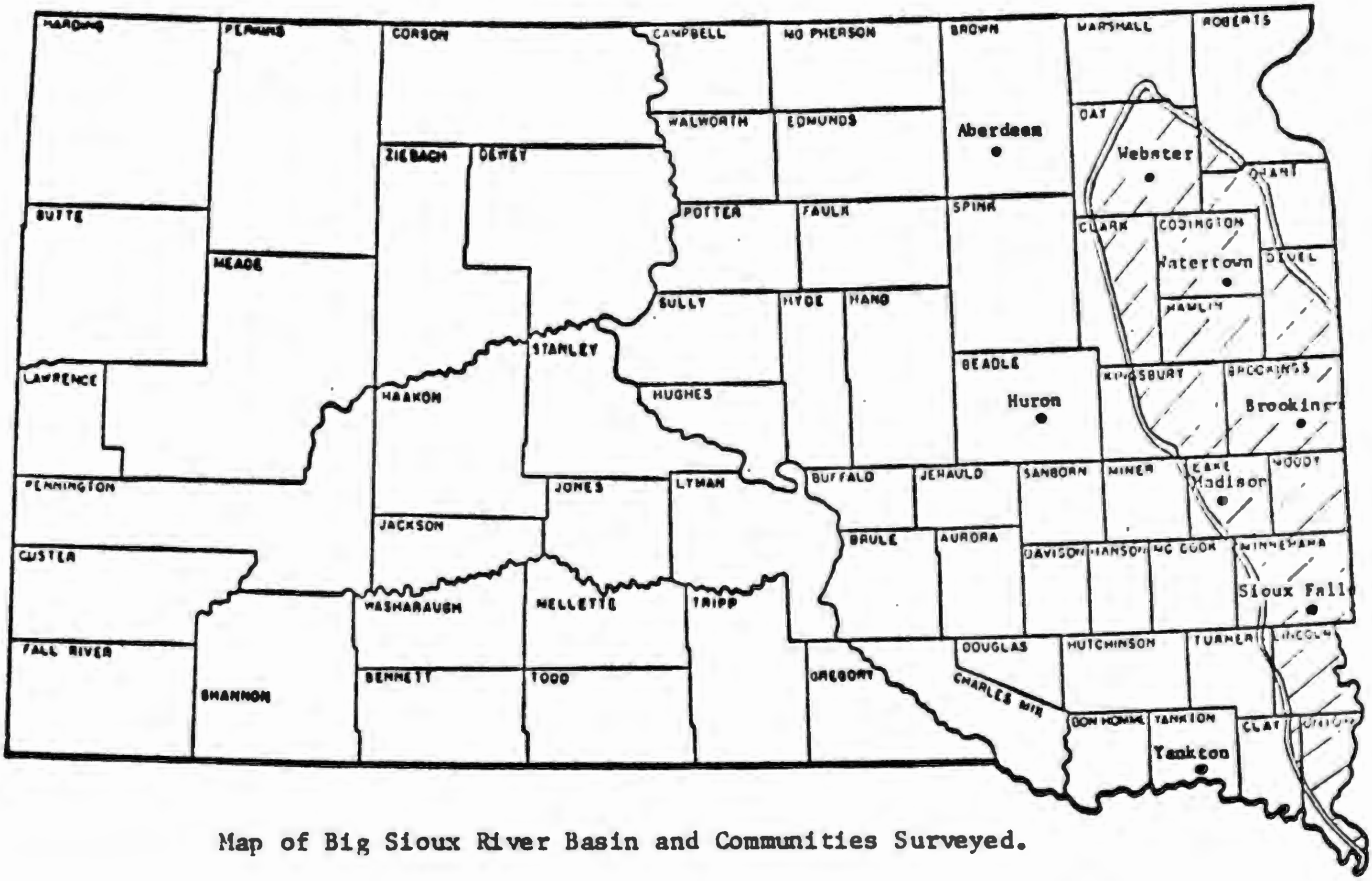
[4] For further information refer to map of Big Sioux River Basin,



Map of Big Sioux River Basin and Communities Surveyed.

For months in which data from several towns were not available, estimated values were generated by observing the percentage increase in residential water consumption over the period where data were available and extrapolating or interpolating the missing data.

Household water consumption data for the months of February, March, and April were averaged to determine the average monthly household water consumption for the spring quarter in each community. The same procedure was used to determine average monthly household water consumption for the summer quarter, (June, July, and August).

The average monthly residential water consumption was expected to be higher in the summer quarter than in the spring quarter. Grima (1972, p. 75) emphasizes this expectation by stating "The composite nature of residential water use makes the demand for this commodity vary with the time of day and year, since the number of water-using appliances and the frequency of their use increases during periods of hot dry weather." The average monthly household water consumption for the sample cities was 1043.66 cubic feet for the spring quarter and 1685.52 cubic feet for the summer quarter.

Price of Water:

In constructing the analytical model, the price variable is of prime importance because price can be most easily adjusted by water utility management when implementing policy. Generally, water rate structures are such that the price variable may be selected from several alternative forms. It is crucial that the researcher specify this variable in a form which truly reflects its impact on the consumer.

Howe and Linaweaver (1967, p. 14) point out, "In studying the impact of price on water demand, the proper concept of price is defined by answering the question, 'what charges can be avoided or changed in magnitude by the decision now being made by the decision-making unit.'" A form of the price variable reflecting only a flat or minimum charge must not be used since the consumer cannot avoid or change this charge by changing water consumption.

The water rate schedule of each study community was available for each quarter included in the study period. Each of the communities incorporated a water pricing policy of decreasing marginal (block) rates which include a minimum charge and decreasing marginal rates for blocks of water used above the minimum quantity.

For example, a minimum charge, which may vary from city to city, covers a specific quantity of water, represented by OX_1 in Figure 2. For any quantity of water equal to or less than OX_1, the customer must pay a charge of P_1 times X_1. When water usage exceeds this minimum quantity, (X_1), a decreasing marginal rate becomes applicable. A charge, levied per unit of water consumed, is applied to water usage exceeding the amount covered by the minimum charge, up to a certain volume.

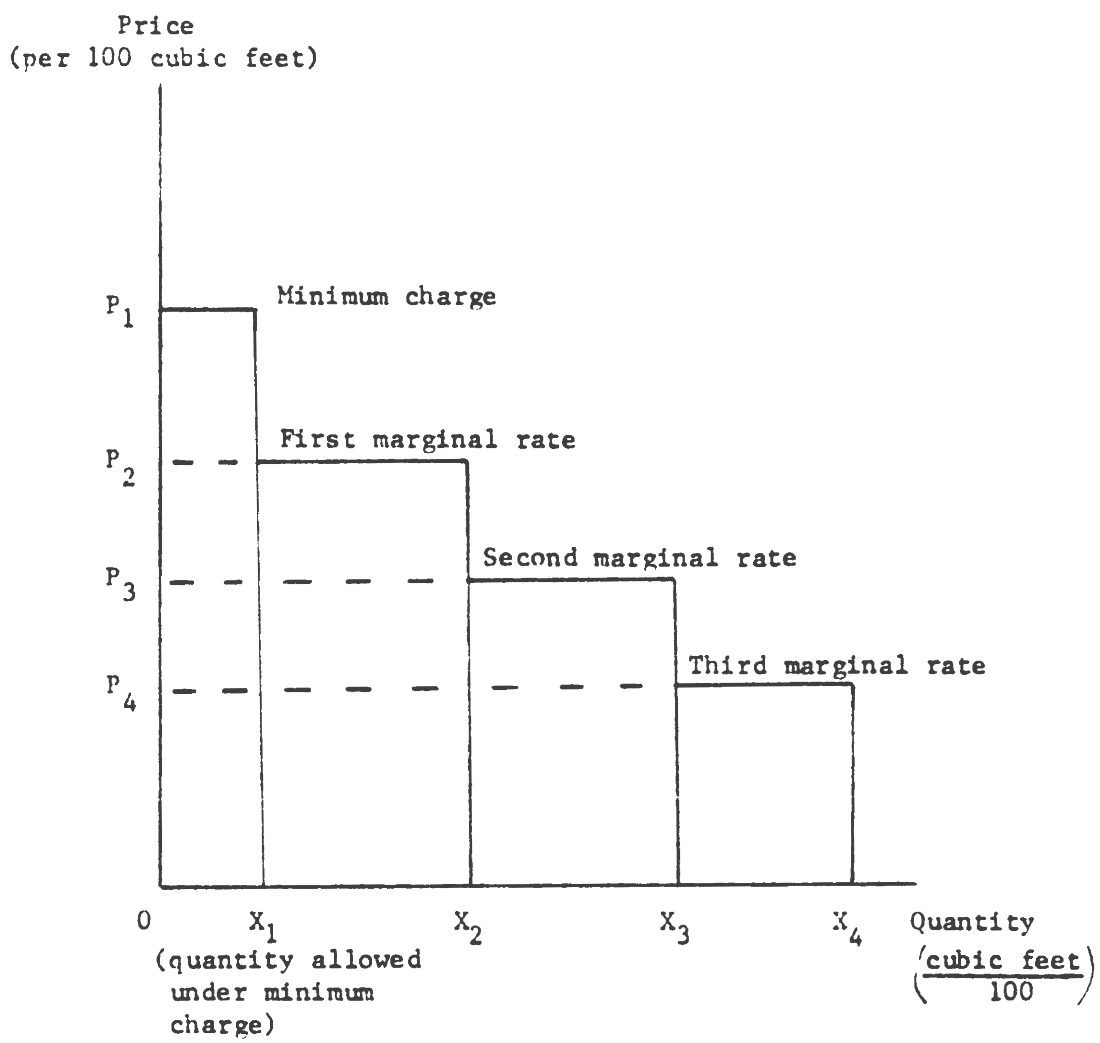


Figure 2. Decreasing Marginal (Block) Rate Structure

The range in which the first marginal price is applicable is the volume from X_1 to X_2.[5] If a household's water consumption exceeds the maximum volume, X_2, covered by the first marginal rate, a second rate is applied for the quantity in excess of the volume covered by both the minimum charge and the first marginal rate. The range in which the second marginal rate is effective is X_2 to X_3. This marginal rate structure may extend over three or four blocks of water, with each subsequent charge being less per 100 cubic feet than the preceding charge.

For this study, two measures of price were incorporated separately in the regression equations. The first measure for price was the average price in each community for the first 1000 cubic feet of residential water. In seven out of eight communities, the consumer would be subject to the first marginal rate. Approximately 500 cubic feet of water were covered by the minimum charge in each community.

A second measure for price was the first marginal price of residential water. Once consumption is in the range where a charge is levied per unit of water consumed, the customer may be influenced in his use of water by the magnitude of this price. Since average residential monthly water consumption never reached a volume in which the second marginal price would become effective in any of the communities, only the first marginal price was considered a possible significant determinant of quantity of water demanded.

Using either technique for price measurement, an inverse relationship with water consumption was expected: higher prices of residential water coincide with lower quantities of water demanded.

Number of Persons per Household:

Data on the average number of persons per household within each community were obtained from the 1970 Census of Population (U.S. Department of Commerce, 1971). Since census data were available for only one year, (1970) figures for this variable were constant from year to year for each city. Variations were evident from city to city, however. It was expected that as the number of persons within a household changes, there should be a direct relationship with that household's water consumption.

Income:

As the income level of a household rises, water consumption may increase. Factors contributing to this would be:

(1) Increased purchases and use of water using appliances such as washing machines, dish washers, and garbage disposals;
(2) More intensive lawn and garden care (sprinkling) in the summer months; and
(3) The overlooking of minor leakages and less careful use of water in sprinkling, bathing, and cooking.

The income variable used in the regression analysis was the average annual per capita income. (South Dakota Business Review, 1977). A positive relationship between the income variable and household water consumption was expected.

Climatic Variable:

It was hypothesized that residential water use in the spring quarter was largely for indoor domestic use and not greatly influenced by climatic factors. However, summer water use, which includes sprinkling, would be affected by climatic conditions.

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[5] The lower bound of the first marginal price in the communities surveyed ranged from 200 cu. ft. to 1000 cu. ft. while the upper bound ranged from 5200 cu. ft. to 13,866 cu. ft. The community of Madison had no upper bound on water use covered by the first marginal price.

Therefore, the climatic variable was included in the summer equations only.

Previous studies have used a wide variety of proxies to represent climate. Results of these studies have shown that generally, the performance of the climatic variable, regardless of the specific variable used was quite similar in water demand studies. Two climatic variables were selected for this study, the average monthly rainfall (U.S. Department of Commerce, 1972-77) and the average monthly rainfall deficiency.

Rainfall deficiency seemed appropriate as a climatic variable because of the positive relationship expected between water consumption and rainfall deficiency and this variable was used in all linear forms of the model. However, because use of the deficiency variable usually resulted in negative numbers, it was inappropriate for use in the logarithmic form (negative numbers cannot be used for logarithms) and the climatic variable was changed to average monthly precipitation. An inverse relationship is expected between average monthly rainfall and water consumption.

EMPIRICAL RESULTS

Analysis of the Linear Model

Table 1 summarizes the regression results obtained using the linear equations. The table shows spring-summer pairs of linear demand equations. Average price for the first 1000 cubic feet of water (P) was used as the price variable for the first pair, while first marginal price (MC) was used for price in pair two.

Only one of the four equations, 1-a, was statistically significant at the 5 percent level. The R^2 value was low at .18 which means only about 18 percent of the change in water consumption is explained by the variables included in this model. The coefficients of all of the variables had the expected sign, with price and income significant at the 10 percent level.

The R^2 value of .19 was highest for equation 1-b but indicates that much of the change in water consumption is still not explained in this equation. Income is the only significant variable at the 5 percent level.

The two equations using first marginal price as the price variable were not significant, had lower R^2 values, and the only significant variable was income. In the spring equation, the price variable had a positive sign which does not correspond with economic theory.

In the only equation where price was significant, the price elasticity co-efficient was -.55 which is consistent with the results of previous studies. With inelastic demand, changes in price will not produce proportionate changes in quantity demanded. Income elasticity coefficients were approximately 1.5, indicating a 10 percent change in income will cause a 15 percent change in water consumption. These findings are also consistent with results of previous studies.

The R^2 values show the percentage change in water consumption which is explained by the variables contained in the model. Low R^2 values that resulted in this study may indicate that variables were omitted which are important determinants of water demand or the variables included were not well measured. The first possibility seems unlikely, however, since the variables included are those which both theory and previous studies have indicated are significant.

Statistically, the first pair of equations appear to provide a better representation of average monthly household water consumption than the second pair. The R^2 values are higher, three of the variables are significant at the five or ten percent level, and the spring equation is significant.

Analysis of Logarithmic Model

A summary of the regression results for the logarithmic equations is shown in

TABLE 1. SUMMARY OF MULTIPLE REGRESSIONS BASED ON LINEAR EQUATIONS

SEASON	INTERCEPT	P	MC	N	C	YCAP	R^2	F VALUE	E_p	E_y
1a SPRING	-856.790	-133.205* (69.124)		320.185 (574.056)		.445* (.238)	.18	3.14**	-.55	1.46
b SUMMER	-2172.370	-122.313 (98.080)		629.378 (797.250)	29.663 (97.641)	.778** (.348)	.19	2.58	-.31	1.50
2a SPRING	-2841.393		822.141 (876.724)	860.690 (636.150)		.316 (.243)	.12	2.08	.25	1.01
b SPRING	-2565.744		-582.661 (1226.185	728.073 (861.424)	51.859 (98.374)	.712** (.349)	.17	2.18	-.10	1.38

F-Value is the variance-ratio.

The numbers in parentheses are the standard errors of estimate of the regression coefficients.

* Indicates significance at the ten percent level.

** Indicates significance at the five percent level.

Note: P = Average price for the first 1000 cubic feet of water
MC = First marginal price for water
N = Number of persons per household
C = Rainfall deficiency
YCAP = Average per capita income
Ep = Price elasticity
Ey = Income elasticity
R^2 = means % of change in water consumption explained by variables included in this model

Table 2. A spring and summer equation are paired. The climatic variable (the average rainfall per month per community) is incorporated in only the summer equation. For the first pair of equations, average price for the first 1000 cubic feet of water was used for the price variable, while for the second pair the first marginal price was used.

While none of the variables were significant at the ten percent level or less, both summer equations were significant at the five percent level. R^2 values were higher for the summer equations in which the climatic variable was included. The expected signs were present for all variables with the exception of the positive sign for the climatic variable and the price variable in the spring equation.

Lack of significance of the variables precludes positive statements about the effect of any of the individual variables on water consumption. However, two of the equations were significant, which indicates a general relationship between the variables included in the model and consumption of water.

Analysis of Variables

Overall, the income variable was generally significant at the five or ten percent level in more equations and was more elastic than the price variables, indicating that changes in income have a greater effect on household water consumption than do changes in price.

While income is not a tool available for water managers to use in reducing or changing consumption of water, knowledge of the relationship between income and water demand can be helpful to the manager in planning. Information on income in each community is usually available to planners.

Average price for the first 1000 cubic feet of water appeared to be a better measure for price than the first marginal price since the R^2 values were higher and the expected sign for the price variable was present in both spring and summer equations when average price was used. Theoretically, first marginal price should explain changes in quantity demanded better than average price since first marginal price may more directly influence the decisionmaker in his use of water. Results from this study did not support this hypothesis, however.

Price is the tool most readily available for use in managing consumption. A strong relationship between price and quantity demanded would imply that it is an effective tool for controlling water use. A strong relationship did not show up in this study, but neither did the study prove that such a relationship did not exist. Even with the weak relationship shown by this study, price can be used as a management tool; however, large changes in price would be needed to bring about a relatively small change in consumption.

Perhaps the observations in this study occurred in the relatively inelastic portion of the demand curve. This part of the demand curve includes the amount of water needed for survival. Persons will consume a minimum amount of water without regard to price. If the mean of the observations had fallen in the elastic portion of the demand curve, a stronger relationship between price and quantity demanded might have been noted.

In both the linear and logarithmic equations, a positive relationship between the number of persons per household and average monthly household water consumption was indicated but this variable was not significant in any of the equations. When analyzing household water consumption, the number of persons per household should affect the amount of water used by that household. However, the form of the data may have contributed to its lack of significance. The average number of persons per household for each town was obtained from the census. Any extreme variability was automatically eliminated by the use of averages. The

TABLE 2. MULTIPLE REGRESSION RESULTS OF LOGARITHMIC FUNCTIONS

	INTERCEPT	PRICE ELASTICITY		INCOME ELASTICITY			MULTIPLE R^2	F VALUE
	a_i	b_i	c_i	d_i	e_i	f_i		
1a SPRING	-.410	-.373		1.480	.827		.148	2.565
		(.251)		(1.411)	(.634)			
b SUMMER	-1.132	-.256		1.309	1.099	.125	.224	3.104**
		(.232)		(1.280)	(.611)	(.150)		
2a SPRING	-.173		.151	2.454	.540		.114	1.903
			(.231)	(1.512)	(.636)			
b SUMMER	-1.099		-.209	1.191	1.028	.111	.218	2.999**
			(.223)	(1.345)	(.602)	(.156)		

NOTE: No variables were significant at the ten percent level. The numbers in parentheses are the standard errors of estimate of the regression coefficients. The F-Value is the variance-ratio.

** Indicates significance at the five percent level.

Variables are as follows:

b_i = Average price for the first 1000 cubic feet of water

c_i = First marginal price of water

d_i = Number of persons per household

e_i = Average per capita income

f_i = Average monthly precipitation

number of persons per household ranged from 2.77 in Webster to 3.25 in Huron, a difference of only .48 of a person which does not reflect the differences that would be found among individual households.

The expected signs for the climatic variable were present in the equations which used average rainfall deficiency but not in those equations which used average monthly rainfall as the climatic variable. The variable was never significant at the ten percent level or less. Perhaps alternative measures of climatic influence, such as temperature or evapo-transpiration, would be better proxies than average rainfall. In the study region, the amount of outdoor sprinkling is affected by temperatures, winds, and evaporation rate as well as amount of rainfall.

Comparison of the R^2 values of the equations show a slightly higher R^2 for the summer equations than the values for the spring equations. The summer logarithmic equation had the highest R^2 value of .224. The summer equations included a climatic variable which the spring equations did not. Since all R^2 values were low, no strong conclusions could be made about differences.

In using time-series data, autocorrelation may be present since many factors affecting residential water use and the disturbance term in one period may extend into the next period when the observations are made on the same community (Danielson,1977). The Durbin-Watson test was used to test the linear model for autocorrelation in the time-series data for selected communities in the study. Results indicated that autocorrelation was present for the spring quarter.

Testing of the summer quarter linear model showed no autocorrelation. The presence of autocorrelation in the spring, but not summer data, may be partially explained by the fact that water use for the spring quarter, largely domestic in nature, can be more influenced by water usuage in previous periods.

The addition or deletion of water using appliances in a household will affect its water use not only during the period of the change but in subsequent periods as well. During the summer months, sprinkling becomes a major factor in household water consumption and is more dependent on factors such as climate and income rather than the volume of water used for sprinkling during the previous year.

The presence of autocorrelation does not affect the values of the derived coefficients, but does bias the standard errors of those coefficients, thereby possibly invalidating their respective tests of significance. Therefore, the coefficients of the independent variables may have in fact been significant, though the tests of significance indicated they were not. When the confidence intervals and tests of significance are invalid, the use of the regression equation for predictive purposes is limited.

Limitations of the Study

Compiling residential water consumption data for each community was the most serious problem encountered. For example, only one of the eight communities surveyed had separate residential water use data. The remaining communities had aggregate consumption figures combining residential, commercial, and industrial water use. In these communities, residential water use was computed by sampling commercial and industrial uses and estimating total water used by these sectors. Estimated total commercial and industrial use was then subtracted from total consumption.

The usual method of distribution of municipal water service to apartment and trailer complexes and multiple family dwelling units caused another problem. Generally, a single connection serves several households and a larger number of persons than is found in a single family dwelling unit. In this study, each connection was treated as a single household. Therefore, the average monthly residential water consumption per household for each city may be slightly inflated.

Each of the observations used in the regression analysis was computed as an average for all households in each city. A drawback in this procedure is that variances in the data are reduced which may partially explain the low R^2 values associated with each equation.

Two characteristics differentiate water from many other goods. First, a minimum amount of water is necessary to sustain life. Demand for the minimum amount is very inelastic; price will have little effect on quantity demanded in low use ranges. Once this minimum amount is consumed, however, other goods may compete with water for the consumer's income. Second, traditionally water has been relatively cheap and becomes cheaper per unit as consumption increases.

Expenditures for water constitute a small portion of consumers' incomes. Unless consumers increase their usage a great deal, that portion of income is not going to increase much, and thus may not greatly affect consumers' demand for water. The averaging of data will conceal any large consumers of water and all resulting observations tend to be in the inelastic portion of the demand curve.

Summary and Implications

Water utility managers in eastern South Dakota can use the results of this project in estimating the effect that factors such as the price of water and consumer income may have on residential water consumption.

Earlier in this paper the need for research of residential water demand was emphasized. It is not always technically possible nor economically feasible to meet increased residential water demand by expanding the supply of water. The alternative is to initiate policies designed to stabilize or reduce consumption.

Previous studies of residential water demand have shown that in many cases the usage of residential water is responsive to changes in price. When the price of water increases, there are no good substitutes for water to which the consumer may turn. There are, however, substitute actions which may be taken to conserve water use and thus reduce consumption, such as by foregoing lawn sprinkling in times of adequate rainfall, repairing minor leakages, and using less water for bathing, cooking and washing purposes.

The first objective of this study was to estimate a demand function for residential water use in spring and summer quarters which would be representative of the average household within the Big Sioux River Basin and adjacent areas. Least squares multiple regression was used to derive both linear and logarithmic forms of the demand function. It was not conclusive which form gave the best representation of demand, since statistical significance and R^2 values were mixed between the spring and summer equations in both the linear and curvilinear equations.

The second objective was to determine significant variables which affect residential water consumption. Two variables, the average price of the first 1000 cubic feet of water and income, were significant in the linear equation. No variables were significant in the logarithmic equation.

The third objective was to derive price and income elasticities which would show the response in water consumption to changes in price and income. Examination of the elasticities of price and income in those equations in which the variables were significant revealed that price elasticity was in the inelastic range, while income elasticity was near unity or in the elastic range. This indicates that for the average household within the study region, water consumption is influenced to a greater degree by changes in income than by changes in the price of water. As income increases more water using appliances may be purchased, greater concern for lawn care may develop, or minor sources of water loss such as leakages may be overlooked.

A policy implication of the study may be that a reduction in residential water use by households in the Big Sioux River Basin could be achieved more quickly and certainly by water use restrictions than by small or moderate increases in the price of water. Water use restrictions have been used by many communities in the survey area.

In 1976, a year characterized by drought conditions, five of the eight communities in the survey enacted a water use restriction policy of voluntary alternate day watering. During that same period, only one community, Yankton, experienced a water price increase, the purpose of which was to generate additional revenue rather than to promote water conservation.

Results of this study do not imply, however, that a proper pricing policy could not or should not be used to achieve changes in water consumption. As noted previously in the sections on empirical findings and limitations of the study, many of the variables were not statistically significant, part of which may be attributed to the form of the data observations. A larger study or a differently conceived study might reveal that proper pricing policies could achieve substantial changes in consumption.

In this study, when price was a significant variable, demand was inelastic. This does not preclude the use of price to achieve changes in quantity demanded, but the change in price may need to be substantial to effect the desired change. Previous studies have resulted in similar findings.

A second policy implication of this study is the effect of income on water consumption. Generally, income was a significant variable in the linear equations. Demand for water was income elastic, which shows that consumption was responsive to changes in income. Since income changes are often a part of the planning effort, the income information should also be used in developing municipal water policies.

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