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This report documents over 50 substantial studies of the response of municipal and industrial water use to price in an attempt to correct the poorly understood phenomenon of the sensitivity of water use to price. Most likely price elasticity ranges are given for non-seasonal and seasonal residential water use; average residential water use; and reported elasticities for industrial and commercial water use.

INFLUENCE OF PRICE AND RATE STRUCTURES ON MUNICIPAL AND INDUSTRIAL WATER USE

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I. INTRODUCTION

THE ROLE OF PRICE

The efficient planning and management of water supply systems is based on a thorough understanding of the use of water and the factors which give rise to it. Forecasting, in particular, requires that the major factors (explanatory variables) be identified and their relationships to water use expressed in quantitative terms. Predictions of future values of explanatory variables, then, can be used to obtain predictions of future levels of water use.

The principal water use explanatory variables are well known, and have been described in other reports (Dziegielewski et al. 1981; Boland et al. 1981; and Boland et al. 1983). In the case of residential water use, for example, they include number of households, population per household, household income, property value, irrigable area, climate, and other factors. Industrial water use is explained by employment, industrial output, recycle ratio, and so forth.

Individual factors vary in importance. Stated in statistical terms, each factor is capable of explaining some fraction, large or small, of the total variance in water use. A factor such as number of residential households, which explains a large fraction of the variance, receives high priority for inclusion in forecasting models. To omit such a factor would be to risk serious error in estimates of future water use. As forecast accuracy becomes more important, and the forecasting method becomes more detailed, additional factors are included. These factors explain progressively less variance in future water use, and, in most cases, their potential contribution to overall accuracy declines accordingly.

While the fraction variance explained is an important consideration in choosing variables for forecasting models, it is not the sole criterion. The degree to which the explanatory variable itself changes in the future is also relevant. For example, irrigable area has been shown to be an important factor in explaining seasonal residential water use. If irrigable area is not expected to change (lot and building sizes remain constant), it may not be necessary to include this factor in the forecast model. Similarily, a factor which explains a small fraction of the variance, but is prone to large fluctuations in value, may be essential to an accurate forecast.

The price of water falls into the latter category. Price explains relatively little variance in water use (compared to such variables as number of households, population per household, climate, etc.). Yet variations in price have been responsible for significant shifts in use levels. Unlike most other factors, price can both increase and decrease and is capable of large and abrupt change. These characteristics give price, as a forecasting parameter, importance beyond its basic explanatory power.

Interest in the relationship between price and water use goes beyond its importance to forecasting. Of all the factors which explain water use, price is frequently the only one within the power of the water supply agency to change (the only decision variable). Changes in water rate level or design alter the prices which users face at the margin and thereby alter the level and pattern of water use. Understanding these interactions is essential to effective rate-making policy as well as supply planning.

Because of the nature of the relationship between price and water use, as well as the abrupt shifts in price which sometimes occur, adjustments to price change are not instantaneous. A change in price brings forth a slow and steady change in water use, which is complete after a period of time ranging up to ten years. Since this adjustment process rarely ends before the next price change occurs, special statistical techniques are often needed to observe the effect of price on water use.

PURPOSE OF THIS REPORT

The characteristics of price as a water use explanatory variable render it uniquely important to water use forecasting, and of considerable interest in other water supply management activities. Price is also capable of large and abrupt changes, and is often associated with a slow and complex response. For all of these reasons, the literature on price and water use probably exceeds, in size and elaboration, the collected discussion of any other single topic pertaining to water demand.

In spite of a relatively large number of useful studies of the effect of price on water use, published summaries have usually failed to reflect the detailed information available or to synthesize that information in a way which is helpful to practitioners. A typical summary table is contained in a previous Corps document (Baumann et al. 1979, 37-39). This table, based on several previously published compilations, simply lists the bare results of 29 previous studies, with minimal information on the type of relationship studied. The results vary widely (elasticities range from 0.00 to -1.41), but no explanation of the cause of this variation is offered.

The casual reader of these summaries could easily draw the conclusion that the sensitivity of water use to price is an uncertain and poorly understood phenomenon. This report is intended to correct that impression. Sufficient work has been completed in the last thirty years to delineate price responses for at least some categories of water use with considerable generality and consistency, as shown in Chapter II. The subsequent chapters discuss the methods and the results of more than 50 studies, organizing the information in a form that will permit forecasters and planners to make useful estimates of probable price effects under a range of local conditions.

The third chapter outlines the major theoretical and statistical considerations in developing and interpreting estimates of the price elasticity of water demand. The fourth chapter discusses the methods used to select, analyze and annotate reports of previous studies; the fifth chapter presents the results of that analysis. A detailed annotated bibliography, which presents a wide range of study results in a standard form and notation, is also provided.

II. CONCLUSIONS

1. Literature

The literature contains more than 50 substantial studies of the response of municipal and industrial water use to price. These include a single study from 1926, followed by some few studies published in the late 1950s and early 1960s. Starting in the later 1960s, interest in this subject increased noticeably, and the number and quality of published studies began a steady increase. The work of Howe and Linaweaver (1967) has long served as a model of high quality analysis, although most articles published since 1980 meet equally high standards of quality.

2. Statistical Deficiencies

Published studies provide results which are subject to a number of qualifications because of statistical deficiencies. These deficiencies originate in sample selection, model specification, choice of explanatory variables, choice of price variable, and level of aggregation. Most studies reviewed gave evidence of at least some difficulties in one or more of these areas.

3. Residential Winter (Nonseasonal) Water Use

Of the available studies of residential winter water use, only one (Howe 1982) appears to be substantially free of statistical deficiency. The results of other studies, after consideration of probable errors or deficiencies, are consistent with the Howe result.

MOST LIKELY ELASTICITY RANGE	(LONG RUN)	0.0 to -0.10
	(SHORT RUN)	n/a

4. Residential Summer Water Use

Available studies support the Howe and Linaweaver (1967) finding of significant differences in price response east and west of the 100th meridian, with respect to summer water use. One substantially reliable estimate of summer season elasticity is available for the eastern U.S.

(Howe 1982). Other studies, after consideration of probable statistical deficiencies, are consistent with this result. No estimates are available for western U.S. summer season elasticities.

MOST LIKELY ELASTICITY RANGE		
(LONG RUN)	Eastern U.S.	-0.50 to -0.60
	Western U.S.	n/a
(SHORT RUN)	Eastern U.S.	n/a
	Western U.S.	n/a

5. <u>Residential Seasonal (Sprinkling) Water Use</u>

As in the case of summer season use, a significant difference is expected between estimates for the western and those for the eastern U.S. All available studies contain at least some deficiencies. It is believed that most resulting errors are upward in direction (estimates are too elastic).

REPORTED ELASTICITY RANGE		
(LONG RUN)	Eastern U.S.	-1.30 to -1.60 *
	Western U.S.	-0.70 to -0.90 *
(SHORT RUN)	Eastern U.S.	n/a
	Western U.S.	n/a

* Study contains statistical deficiencies which may lead to error in the price elasticity estimates.

6. <u>Residential Average Water Use</u>

The elasticity of average annual residential use reflects (approximately) an average of the winter and summer price responses (or, seasonal and nonseasonal responses). Since summer season responses vary spatially, and the importance (weight) of the summer season varies with climate, results for average water use are not expected to be as reliable as those for narrower definitions of water use.

Most studies in the literature address residential average water use. Only a few of these are substantially free of error from one source or another, however. The studies which contain statistic deficiencies are consistent, after consideration of the probable direction and magnitude of resulting errors, with the unbiased studies.

MOST LIKELY ELASTICITY RANGE	
(LONG RUN)	-0.20 to -0.40
(SHORT RUN)	0.0 to -0.30

7. Industrial Water Use

Very little attention has been given to the price response of industrial customers of municipal water systems. Available studies suffer from deficiencies of various types, but do show significant differences among the various categories of industrial user. Studies of aggregate industrial use show, as expected, considerable variation from place to place as the mix of industrial use changes. In general, industrial water use is more elastic than residential use.

REPORTED ELASTICITY RANGE (LONG RUN)		
Individual categories	-0.30 to -6.71	*
Aggregate industrial	-0.50 to -0.80	*
(SHORT RUN)		
Individual categories	n/a	
Aggregate industrial	n/a	

* Study contains statistical deficiencies which may lead to error in the price elasticity estimates.

8. Commercial Water Use

The literature contains a single study (Lynne et al. 1978) of the price response of commercial water users, based on cross-sectional data from Miami, Florida. That study contains statistic deficiencies of various kinds, but does show significantly different elasticities for various categories of commercial use. This suggests that aggregate commercial/institutional studies, were they available, would show considerable variation in price response from place to place.

REPORTED ELASTICITY RANGE (LONG RUN)		
Individual categories	-0.20 to -1.40	*
Aggregate commercial	n/a	
(SHORT RUN)		
Individual categories	n/a	
Aggregate commercial	n/a	

* Study contains statistical deficiencies which may lead to error in the price elasticity estimates.

III. PRICE ELASTICITY OF DEMAND

DEFINITION

The Demand for Water

Water is used for many purposes, ranging from human consumption (drinking) to irrigating lawns and gardens. While it is sometimes argued that water is uniquely essential to human life, the quantity required to sustain life is small (less than two liters/person/day) and can be easily supplied by means other than public distribution systems (in food, as bottled water or soft drinks, etc.). Water distributed by public systems, therefore, is an economic good like any other. Water is purchased and used in a way not fundamentally different from the consumption of bread or gasoline or any other staple commodity.

The quantity of water allocated to each use is affected by a number of factors or explanatory variables; when all uses are considered, a relatively large number of explanatory variables can be found to have some influence on the level of water use. There are two general categories of explanatory variables: (1) those which determine the need for water and (2) those which determine the intensity of use of water. "Need" variables include population served, number of households, industrial employment, etc. The presence of these factors indicates that water-using activities are occuring and that some water will be required. It is not clear from evidence of "need" alone how much water will actually be used.

The remaining variables determine intensity of use and include such factors as income (ability to pay for water), conservation practices (willingness to substitute inconvenience or other inputs for water use), and price (willingness to pay for water). For a given set of water-using activities ("need"), water use will increase with increasing income, decrease with increasing conservation activity, and decrease with increasing price.

Economists define the demand for water as the relationship between water use and price, when all other factors are held constant. Demand is a negative functional relationship, illustrated by the demand curve, shown as figure III-1. This curve describes the relationship between price and water use for a single user. The demand imposed by each water user can be represented by a similar demand curve, and all such curves are expected to be negatively sloped (increased price results in decreased water use).

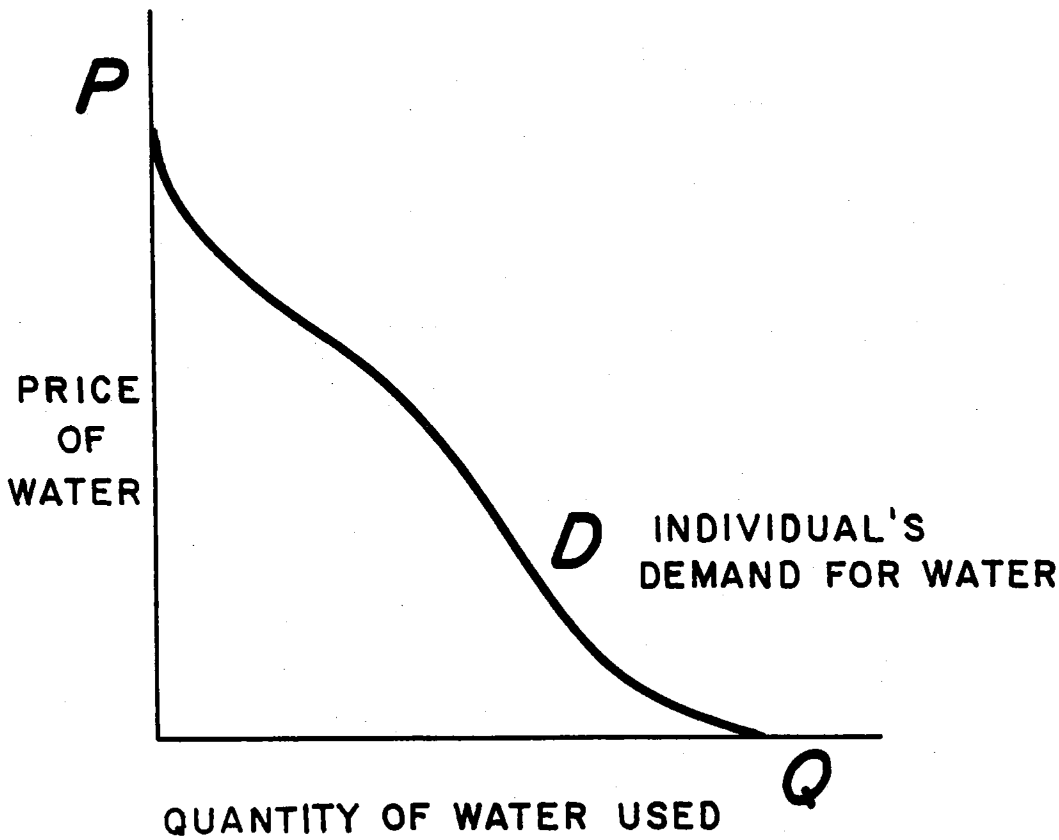

Figure III-1. Individual Demand Curve

When a number of users face a price which is uniform over the group, their individual demand curves can be summed horizontally to obtain an aggregate demand curve, as shown in figure III-2. The aggregate demand curve, usually called a market demand curve, is also negatively sloped. It can be seen that there is a price (P') at which no one will purchase water from the public system (they would prefer to obtain water by other means). Also, in the event that no price is set (price = zero), a finite quantity of water will be demanded (shown as Q'). Between these two extremes, the quantity of water demanded is determined by the price and the demand curve, if all other factors are held constant.

The shape and position of the demand curve are determined by the values of the other explanatory variables, including the "need" variables and income and conservation practices. The effect of increasing income is to shift the curve to the right (see figure III-3), so that the same price (P_0) would result in progressively larger quantities of water being used (Q_1, Q_2, Q_3). The effect of increasing conservation activity is to shift the curve to the left (figure III-4). Similarly, increasing the levels of the "need" variables will, generally speaking, move the demand curve to the right. All of these shifts may be accompanied by changes in the shape and slope of the demand curve, as indicated in figures III-3 and III-4.

Water supply planning rarely requires that the entire demand curve be known. More often, it is sufficient to know how specified incremental changes in explanatory variables will affect water use. In the case of price, this information is contained in the slope of the demand curve. The slope gives the incremental change in water use for an incremental change in price, at some position on the curve (see figure III-5).

Because of the units chosen for the axes of the demand curve (dollars per unit of water use, and units of water use), the slope of the curve has an inconvenient dimension (dollars per unit of water use squared). It is customary, therefore, to use a dimensionless measure of the relationship, found by dividing fractional (instead of incremental) change in water use by fractional change in price. This dimensionless measure is known as an elasticity, here called the price elasticity of water demand. It is defined for an arc of the curve, as shown in figure III-5, as:

$$\eta = \frac{\dfrac{Q_2 - Q_1}{Q^*}}{\dfrac{P_2 - P_1}{P^*}} \qquad (1)$$

Where:

$$Q^* = \frac{Q_2 + Q_1}{2}$$

$$P^* = \frac{P_2 + P_1}{2}$$

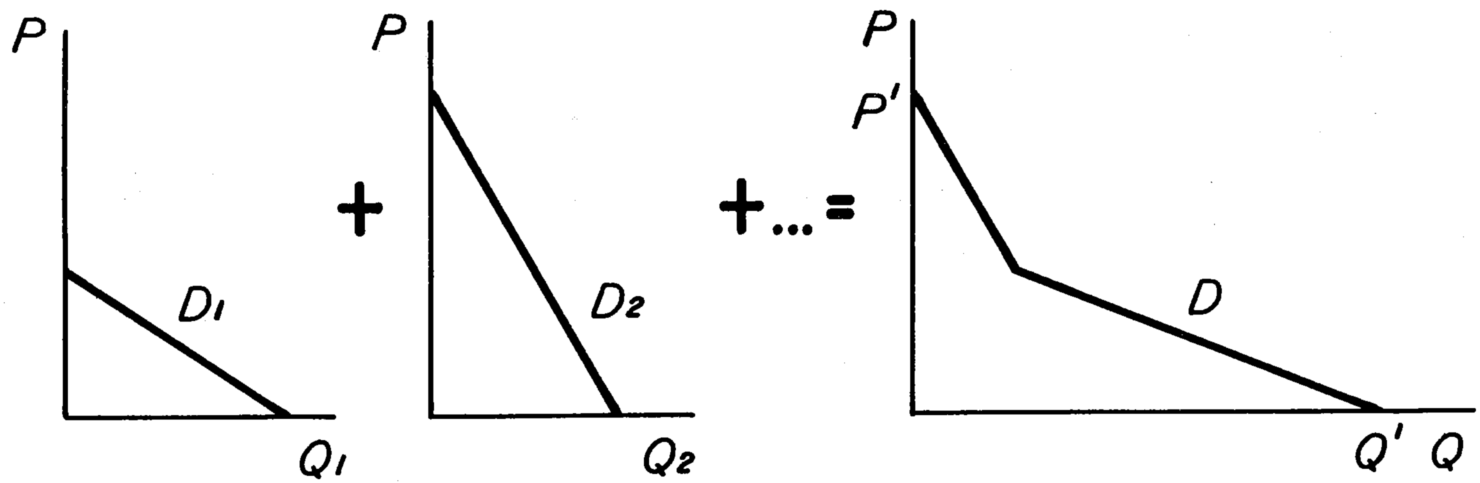

Figure III-2. Aggregate Demand Curve

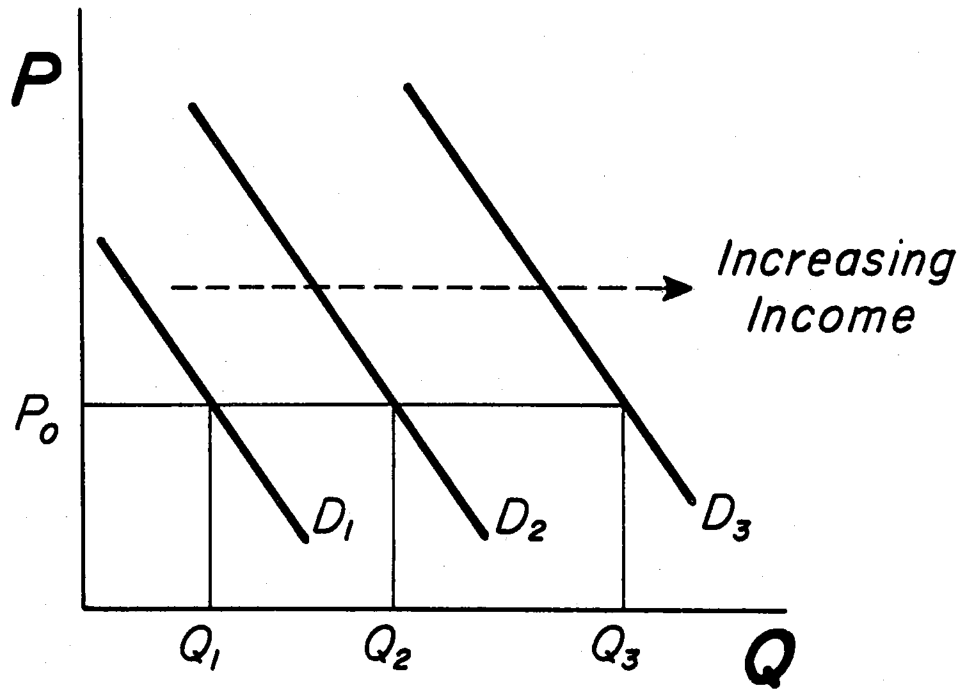

Figure III-3. Effect of Income on Demand

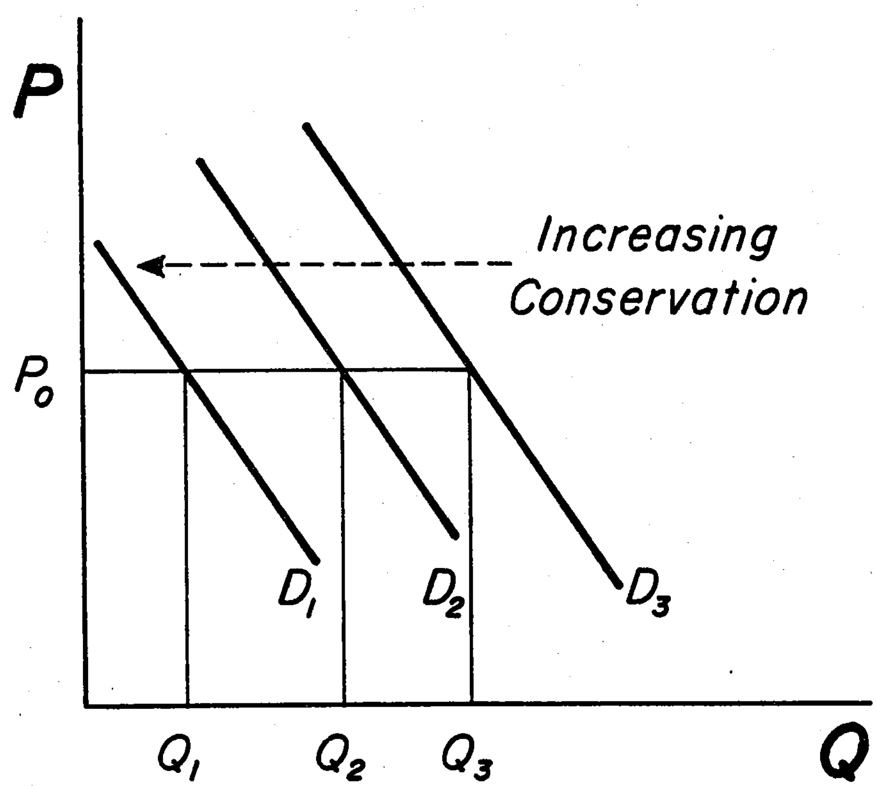

Figure III-4. Effect of Conservation Practices on Demand

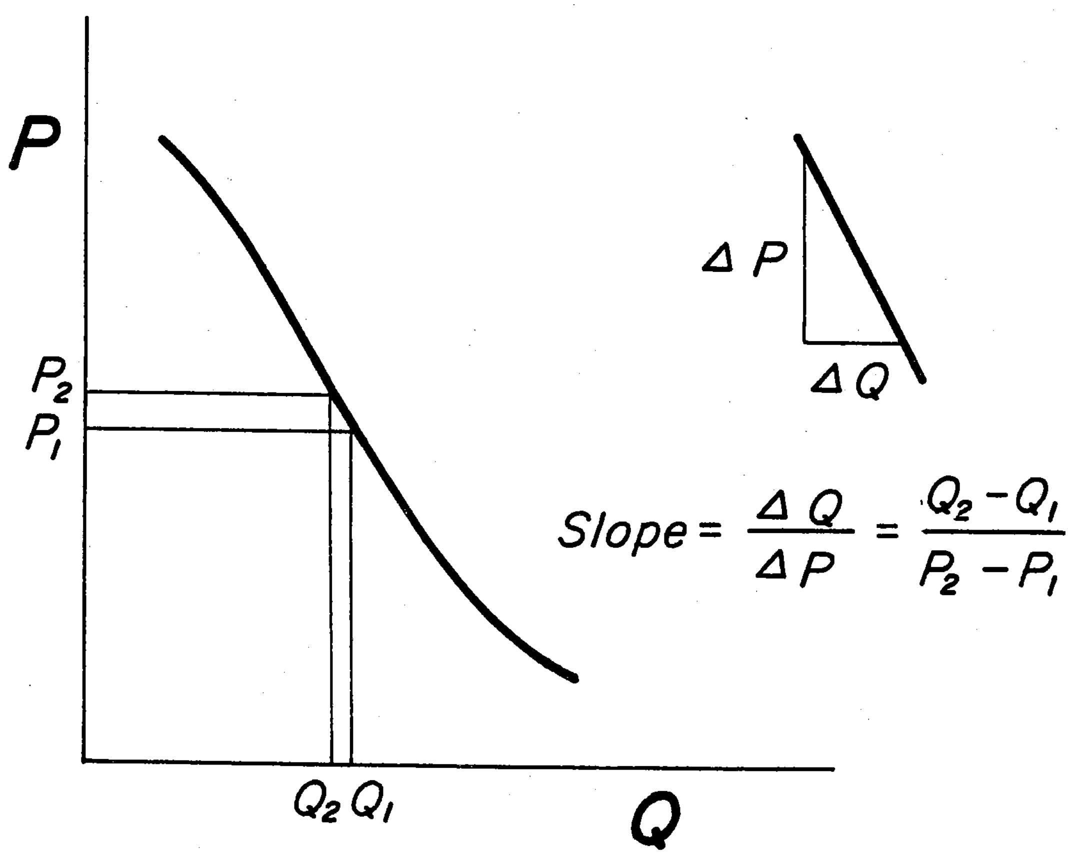

Figure III-5. Definition of Scope of Demand Curve

A more frequently used definition is based on the derivative of the demand function, and yields the elasticity at a specific point on the curve as follows:

$$\eta = \frac{dQ}{dP} \frac{P}{Q} \qquad (2)$$

Where water use is a function of price and other variables, the ordinary derivative in (2) is replaced with a partial derivative:

$$\eta = \frac{\partial Q}{\partial P} \frac{P}{Q} \qquad (3)$$

Both definitions give a dimensionless elasticity, which is expected to be a negative quantity (because the demand curve is negatively sloped). Price elasticity may be interpreted as the percentage change in quantity which would result from a one percent change in price. A price elasticity of -0.5, therefore, indicates that a 1.0 percent <u>increase</u> in price would be expected to result in a 0.5 percent <u>decrease</u> in quantity demanded (use). Conversely, a 1.0 percent <u>decrease</u> in price would produce a 0.5 percent <u>increase</u> in quantity demanded.

In order to distinguish different types of response to price, the following terms are used, depending on the magnitude of the calculated elasticity:

$\eta = 0.0$	perfectly inelastic (zero elasticity)
$0.0 > \eta > -1.0$	relatively inelastic
$\eta = -1.0$	unitary elasticity
$-1.0 > \eta > -\infty$	relatively elastic
$\eta = -\infty$	perfectly elastic (infinite elasticity)

In other words, demand is said to be relatively inelastic when quantity changes less than proportionately with price, and relatively elastic when quantity changes more than proportionately with price.

FACTORS INFLUENCING PRICE ELASTICITY

User Class

Water is used by many different types of users and for many different purposes. Each of these uses is associated with a (possibly different) set of explanatory variables, and may be affected differently by any of them. For purposes of analysis, water users are usually grouped into categories according to similarity of use types. Among the usual categories, or user classes, are single-family residential users, multi-family residential users, commercial and institutional users, industrial users, etc.

Because the relationships existing between explanatory variables and water use are possibly different for different user classes, the price elasticity of demand may be different as well. For this reason, studies are usually confined to a single, reasonably homogeneous user class. Results obtained for a specific user class are only applicable to that user class and not generally transferable to other groups of water users.

Where price elasticities of aggregate water use are reported, they approximate weighted averages of the elasticities of the component user classes. Since the weights vary from community to community according to the relative size of the classes, consistent estimates of elasticities of aggregate demand would not be expected.

Season

Even though user classes are defined to be as homogeneous as possible, there are still many different uses, affected by different explanatory variables, within each class. One method of further clarifying basic relationships is to separately analyze summer and winter (or, sometimes, seasonal and nonseasonal) water use within a class. This isolates the relatively more homogeneous winter (or nonseasonal) water use from the summer (seasonal) use, which includes various irrigation and outside uses.

Since the components of water use vary by season, the relevant explanatory variables, and their relationships with water use, vary as well. Price elasticity of demand, therefore, can be expected to vary between summer and winter (or seasonal and nonseasonal) water use.

Changes in Explanatory Variables

Since price elasticity of demand is defined at a particular point along a demand curve, a different value may be found at another point. If the demand curve is linear, for example, price elasticity would become more negative with increasing price, or less negative (closer to zero) with decreasing price (see figure III-6). Other equally plausible demand curves can be constructed with the same elasticity at every point (figure III-7), or with elasticity that becomes more negative with decreasing price. In general, elasticity may increase, decrease, or remain the same with decreasing price level.

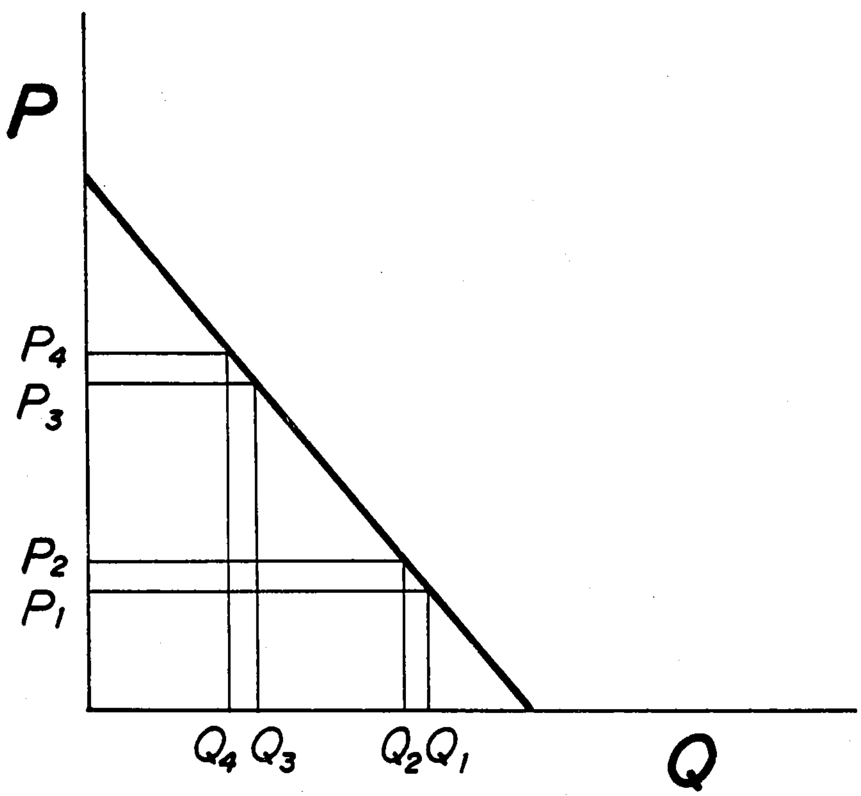

Figure III-6. Linear (Constant Slope) Demand Curve

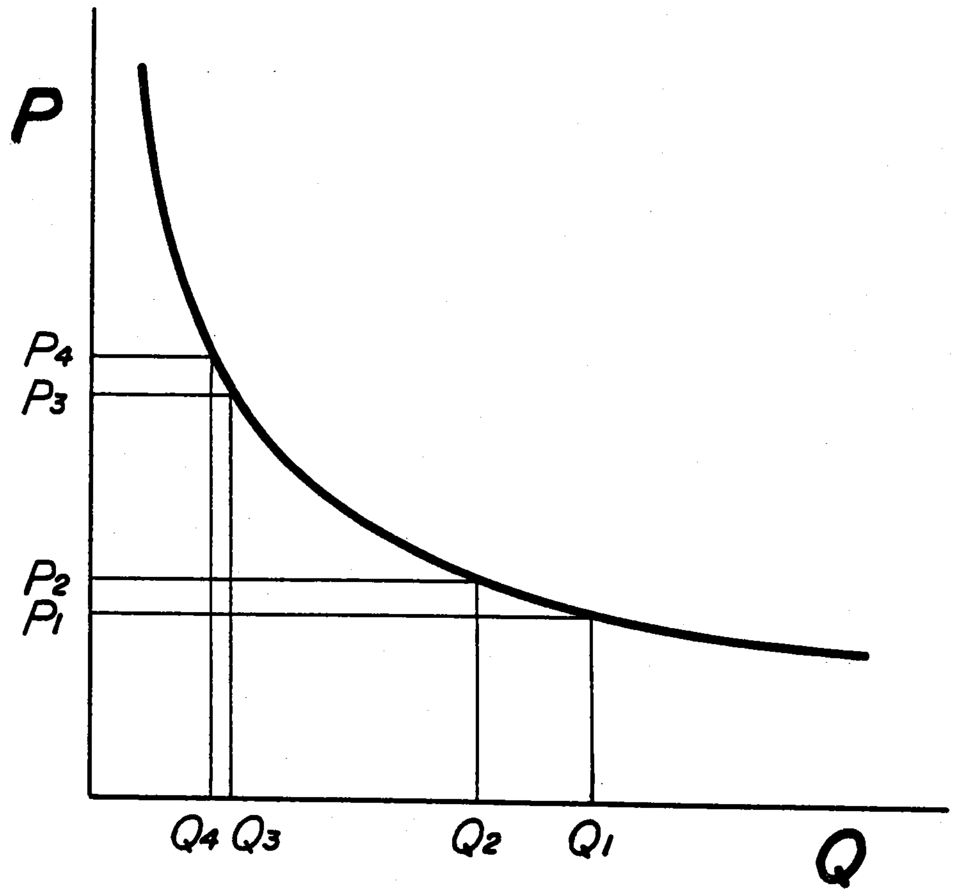

Figure III-7. Exponential (Constant Elasticity) Demand Curve

As noted above, demand curves depend upon the values of all other variables which determine water use. Figures III-3 and III-4 show this relationship for changes in income and conservation. Since the demand curves are changed in location and (possibly) shape, the value of price elasticity of demand may change as well. As in the case of price changes, there is no a priori assumption regarding the direction of elasticity changes in response to changes in other explanatory variables.

Long-Run vs. Short-Run

Elasticity also varies according to users' ability to make cost-effective adjustments in the use of related goods and in habits. In the case of water, this may include changes in the stock of water-using appliances, changes in landscaping, changes in irrigation practices, changes in domestic water use habits, etc. When the user is free to adjust any related good or behavior, the measured adjustment to price is described as a long-run elasticity. When one or more of the adjustments is not available for any reason, the adjustment is measured as a short-run elasticity.

Since adjustments to water price all require the passage of time, perhaps up to a decade (changes in the stock of major water-using appliances), long-run and short-run response become synonymous with long-term and short-term response, respectively. Although the terms have distinct meanings, they will be used interchangeably here.

It is expected that long-run responses will be more elastic (elasticity will be more negative) than short-run responses, although the difference may not be large in every case. It is also expected that a number of years may have to elapse before the long-run response can be presumed complete. The short-run response may be evident within weeks or months of the effective date of a price change.

Exceptions to these generalities should be noted. Changes in water price do not affect all users simultaneously. Typically, a change is announced to be effective for all meter readings or bills occurring after a certain date. Depending upon the meter-reading cycle and the billing lag, it may be four months or more before all customers actually receive a bill calculated according to the new rates.

Two different, and sometimes contradictory, responses may be observed. First, some users may react immediately on hearing of the new rate, even before it actually takes effect. This early response, the "announcement effect," is based on the expected, rather than actual, impact of the new rates. To the extent that the perceived impact is greater than the ultimate reality, the initial response may be greater than the later net adjustment. On the other hand, if the initial expectation underestimates the impact of the rates, the first response may be a smaller adjustment than that later adopted.

Second, other users may ignore or be unaware of the announcement, postponing their response until the first bill is received at the new rates. On seeing the impact of the rates, they may undertake a series of short-run, then long-run, adjustments as described above. Prior to the receipt of the first bill, however, there has been no change in water use patterns, even though the new price is in effect.

Attempts to observe short-run elasticities by means of time-series analysis over periods of less than one year may be confounded by these problems. Some users may have reacted to the announcement, sometimes overestimating and other times underestimating the actual impact of the price change. Other users may not react at all until the first bill arrives. These users' reactions are phased into overall water use statistics gradually, as the meters are read and the bills rendered. Observed progression from an initial short-run to a long-run response may, therefore, be distorted by the billing cycle.

EMPIRICAL ESTIMATION

Method

Estimates of price elasticity are obtained by econometric analysis of price-quantity data for samples of water users. In order to interpret the data, it is necessary to postulate the existence and the specific functional form of a demand function. This permits the parameters of the function to be estimated by statistical analysis, usually multivariate regression. Once the parameters are known, the price elasticity can be calculated, using one of the definitions provided above.

Since the various explanatory variables are typically and sometimes strongly correlated with each other, it is helpful to collect data on all important explanatory variables, so that as many related factors as possible can be included in the multivariate models. Also, since some explanatory variables may not be identified (because of oversight or lack of data), complete analysis requires consideration of the consequences of omitting relevant variables.

Demand models may be estimated from primary (collected for the purpose, perhaps using specially-installed meters) or secondary (collected for another purpose, usually billing) data. In all cases, water use data are usually of moderate-to-poor quality. Observations are frequently missing, and reported observations may be incorrect. Secondary data may contain estimates of water use (where meter readings were not available) and the period covered by each water use observation (the billing period) may be irregular.

Observations of explanatory variables may also suffer from quality problems. In some cases, the variables are poorly specified: the defined variable may be similar to, but not the same as, the variable actually presumed to affect water use. Residential households differ in their capacity to use water as a consequence of differences in life-style and available water-using appliances. This variable cannot be measured directly, so it is usually approximated by such variables as housing value, household income, number of appliances, educational attainment, socio-economic class, etc. While each of these may capture some part of the relationship of interest, none of them is identical to the true explanatory variable.

As a result of missing or poorly specified data, most empirical water use functions leave a significant fraction of the variance in water use unexplained. The problem is most noticeable for analyses based on cross-sectional data, where the missing variables are more likely to affect the results.

Functional Forms

As noted above, the form of the water use function must be specified in advance, so that its parameters may be estimated from the data. While many forms are possible, multivariate regression studies have usually focused on a few basic variants. These are based on the linear regression algorithm and differ only in the mathematical transformation used to achieve linearity. Other functional forms are occasionally used in conjunction with statistical techniques other than multivariate linear regression.

In describing the frequently used functional forms, the following notation will be used:

Q = quantity of water used

P = price of water

I = relevant measure of income

X = vector of other explanatory variables

z = error term

a, b, c, d = regression coefficents

$\overline{Q}$, $\overline{P}$, etc. = means of quantity, price, etc.

ln( ) = natural (Napierian) logarithm

e = base of Napierian logarithms (= 2.7183...)

Linear Function

The simplest form of water use function uses no transformation at all; it is simply a multivariate linear relationship:

$$Q = a + bP + cI + dX + z \qquad (4)$$

When income and other explanatory variables are held constant, (4) reduces to the following expression for a linear demand curve:

$$Q = a' + bP \qquad (5)$$

Where: $a' = a + c\bar{I} + d\bar{X}$

$\bar{z} = 0$

Price elasticity of demand, at any selected set of values for Q and P, is calculated from (4) as follows:

$$\eta = b\frac{P}{Q} \qquad (6)$$

In most cases, the elasticity is calculated at the means ($\bar{Q}$, $\bar{P}$).

An example of a linear demand function can be found in Howe and Linaweaver (1967), who reported the following relationship for nonseasonal use by single-family households:

$$Q = 206 - 1.3P + 3.47I \qquad (7)$$

The price elasticity of demand at the mean can be calculated if the mean values of water use and price are known. In this case, they are 206 gallons/day and 40.1 cents/1,000 gallons, respectively. The price elasticity is, therefore:

$$\eta = -1.30 \frac{40.1}{206} = -0.2307 \qquad (8)$$

Elasticities could be calculated at other points on the demand curve by supplying the corresponding values of Q and P. Since the elasticity depends upon the value of P (and, therefore, Q), however, differences between two independent studies may be explained, in part, by differing price levels. It could be helpful, in this case, to compare elasticities calculated at the same price level. Where the means differ significantly, however, the possible error associated with the estimate of the regression line increases rapidly for prices which diverge from the mean.

Log-Linear Model

A log-linear demand function is similar to a linear function, except that the dependent variable (Q) is replaced with its log transform (usually, its natural logarithm). This yields the following form:

$$\ln(Q) = a + bP + cI + dX + z \tag{9}$$

Taking the antilog of both sides would give:

$$Q = e^{a + bP + cI + dX + z} \tag{10}$$

Holding all factors except price constant yields the equation of the demand curve:

$$Q = a' * e^{bP} \tag{11}$$

$$\text{Where } a' = e^{a + c\overline{I} + d\overline{X}}$$

$$\overline{z} = 0$$

The price elasticity of demand, based on expression (10), is:

$$\eta = bP \tag{12}$$

An example of a log-linear model is offered by Gibbs (1978), who developed the following expression

$$\ln(Q) = 3.12 - 1.85P + 0.00004I \tag{13}$$

The elasticity, at the mean price of 28 cents/1,000 gallons, is:

$$\eta = -1.85P = -0.51 \tag{14}$$

As in the case of the linear model, price elasticity for the log-linear function is a function of price. In this case, however, elasticity is directly proportional to price.

Log-Partial Log Model

A further variant of the log-linear form includes log transforms for the dependent and some, but not all, of the right-hand-side (explanatory) variables. An example of this form is:

$$\ln(Q) = a + bP + c\ln(I) + d\ln(X) + z \tag{15}$$

The alternative form is:

$$Q = e^{a + bP + z} * I^c * X^d \tag{16}$$

The demand curve, holding I and X constant, would have the following form:

$$Q = a' * e^{a + bP} \tag{17}$$

Where: $a' = I^c * X^d$

$\overline{z} = 0$

As in the case of the log-linear model, the price elasticity of demand is directly proportional to price:

$$\eta = bP \tag{18}$$

Foster and Beattie (1979) provide an example of a log-partial log function:

$$\ln(Q) = -1.3895 - 0.1278P + 0.4619 \ln(I) + d \ln(X) \tag{19}$$

The price elasticity, calculated at the mean price of $3.67/1,000 gallons, is:

$$\eta = -0.1278 * 3.67 = -0.469 \tag{20}$$

Double-Log Model

The final variant of this class of demand functions is a multivariate linear model with all variables replaced with their log transforms. The model has the following form:

$$\ln(Q) = a + b \ln(P) + c \ln(I) + d \ln(X) + z \tag{21}$$

This can also be written as:

$$Q = a' * P^b * I^c * X^d$$

Where: $a' = e^{a + z}$ (22)

The two-parameter demand curve (with other variables held constant) is:

$$Q = a'' * P^{b} \tag{23}$$

Where: $a'' = e^{a} * \bar{I}^{c} * \bar{Z}^{d}$

$\bar{z} = 0$

The price elasticity of demand of the double-log model has a very convenient form:

$$\eta = b \tag{24}$$

Elasticity, therefore, is constant and independent of the values of P or Q. It is not necessary to decide which value of P to use for the calculation, and results from independent studies can be more easily compared to one another.

An example of a double-log model can be found in Billings and Agthe (1980):

$$\ln(Q) = -7.36 - 0.267 \ln(P) + 1.61 \ln(I) - 0.123 \ln(D) + 0.0897 \ln(W) \tag{25}$$

This model can also be written:

$$Q = 0.0006362 * P^{-0.267} * I^{1.61} * D^{-0.123} * W^{0.0897} \tag{26}$$

The value of the price elasticity of demand is, therefore:

$$\eta = -0.267 \tag{27}$$

OTHER ISSUES

Bias

Multiple regression demand models of the type shown above, provide valid estimates of the price elasticity of demand provided that certain conditions are met. These include:

1. The functional form is properly chosen.

2. The variance of the dependent variable is unrelated to the values of the explanatory variables (homoscedasticity).

3. The dependent variable (given values for the explanatory variables) is normally distributed.

4. The residuals are not autocorrelated.

5. All significantly correlated explanatory variables are included.

6. All included explanatory variables are correctly specified.

Failure to satisfy these requirements may affect the efficiency with which the price coefficient is estimated (resulting in incorrect measures of reliability or goodness of fit), or it may affect the value of the price coefficient itself. In the latter case, the estimate of the coefficient is systematically in error, or biased.

Bias in the price coefficient can arise from a number of sources, but the most frequent causes include improperly defined or selected data samples, omission of one or more variables which are correlated with water use and collinear with price, and incorrectly specified price variables.

Price Variable Specification

While most economic goods are sold to consumers at well-defined prices, water is priced by means of relatively complex rate schedules. These schedules may include a number of fixed charges--including assessments, service charges, minimum charges, etc.--as well as a number of variable charges. The variable charges may differ from one group of users to another (class rates), from one block of use to another (decreasing and increasing block rates), or from one season to another (seasonal rates).

Economic theory states that the price which affects the level of use is the price paid at the margin, i.e., for the last unit used. Depending upon the structure of rates, this price may vary from user to user, or from time to time for the same user. It may be difficult or impossible to determine the marginal price associated with each observation of water use. For example, when water use is aggregated over a number of users who face block-type rates, marginal price data are inevitably lost. For these reasons, many studies rely on measures of average price, sometimes calculated as total revenue from charges divided by total water sold.

When time-series data are used, price data must be deflated to a constant dollar measure, using some suitable index. National or local consumer price indices are most often used for this purpose. In the case of seasonal rates, it may be necessary to develop measures of price which account for lags in the billing cycle, and the perception of users regarding cyclical changes in price.

The correct specification of price is of fundamental importance in estimating price elasticities. Even where price has been correctly specified, however, the characteristics of the rate structure may introduce bias. When decreasing block designs are used, for example, the marginal price decreases as more water is used. This insures a negative functional relationship between price and use, even if customers are completely insensitive to price. Data collected from individual customers facing such a rate will, therefore, inevitably overestimate price elasticity.

Another characteristic of block-type rate structures is a relatively large gap between marginal price and average price. Customers served by different utilities, on different rate schedules, may pay the same marginal price but quite different total bills (average prices). Such customers would not be expected to exhibit identical water use, other things being equal, either because of different perceptions of price or, more likely, because of different residual incomes. In order to deal with this problem, a special construct, Nordin's bill difference variable (Bell Journal of Economics 7 [1976]:719-21), is used to measure differences in residual income. The bill difference variable is defined as:

$$D = TB - (Q^*P_m) \qquad (28)$$

Where: TB = total bill during billing period

Q = total water use during billing period

P_m = effective marginal price of water during billing period

Using the bill difference variable and marginal price, the demand function takes the following form:

$$Q = a + bP_m + cI + dX + eD \qquad (29)$$

The calculation of price elasticity must be altered, however, since D is itself a function of price. An example of this calculation is provided by Howe (1982). He describes a decreasing-block design with a fixed service charge and a customer whose use extends to the second block, where:

$$D = TB - (Q^*P_m) = [SC + Q^1 * P_{m1} + (Q - Q^1)^*P_m] - Q^*P_m \qquad (30)$$

Where: SC = service charge per billing period

Q^1 = quantity of water allowed in first block

P_{m1} = marginal price in first block

P_m = marginal price in second block

which simplifies to:

$$D = SC + Q^1(P_{m1} - P_m) \tag{31}$$

Substituting (31) into (29), taking the partial derivative with respect to P_m, and using the definition of price elasticity given as expression (3), the following is obtained:

$$\eta = \frac{Q}{P_m}\,\frac{P_m}{Q} = (b - dQ^1)\,\frac{P_m}{Q} \tag{32}$$

If elasticity is to be estimated at the means, the appropriate values must be provided for price and quantity. Note that the size of the first block (Q^1) must be expressed as units of use per billing period to agree with the dimension of regression coefficient d.

Howe obtained the following expression for a similar application (for users in the second block of a decreasing-block rate structure):

$$Q = 234.0 - 127.9\ P_m + 4.04I - 7.20D \tag{33}$$

Where Q^1 = 12.75 units (1,000 gallons) per billing period, and the means of water use and second block price are 261 gallons/day/dwelling unit and $0.40/1,000 gallons, respectively, the elasticity at the means is:

$$\eta = [-127.9 - 12.75*(-7.20)] * \frac{0.40}{261} = -0.055 \tag{34}$$

It should be noted that if the bill difference variable had been omitted (and the same coefficient obtained for the price term), the elasticity would have been estimated at -0.196, a significant overestimate.

Collinearity

Explanatory variables are chosen because they are believed to be correlated with water use. Unfortunately, when two or more explanatory variables are used in the same water use model, they are often correlated with each other (collinear). When collinearity is pronounced, the first variable to enter the regression equation will assume a coefficient which expresses its own relationship to water use and, to some degree, the relationship of the correlated variable. Bringing the second variable into the equation may make only a small improvement in the fraction of variance explained, but the value of the coefficient of the first variable will change markedly. Collinearity creates ambiguity regarding the meaning and significance of the coefficients of collinear variables and causes those coefficients to be unstable.

Time-Series Analyses

When water use data consist of successive observations over time for the same users, collinearity may lead to a special set of problems. Most, if not all, explanatory variables are strongly correlated with time. Since all observations in a time-series analysis have the time sequence in common, they are likely to be highly correlated with each other. The possibility of biased or inefficient coefficient estimates is enhanced by the fact that even borderline explanatory variables, not considered for inclusion in the model, may be strongly correlated with the variables that are included.

Problems with missing variables may be detected by analyzing the regression residuals for serial correlation. Statistical tests are available (e.g., the Durbin-Watson test) to identify significant serial correlation. In the event of positive results, adjustments should be made to the regression model to minimize bias in coefficient estimates and in significance tests.

IV. RESEARCH METHOD

LITERATURE SEARCH

A review of the literature was carried out in order to identify significant studies of the effects of price, rate structures, and pricing policies on municipal and industrial water use.

Computer searches of two independent data bases were conducted in order to prepare the initial listings of studies to be reviewed. The first data base was the Selected Water Resources Abstracts developed and maintained by the Water Resources Scientific Information Center of the U.S. Department of the Interior. The second search used the data base of the American Water Works Association, maintained by the AWWA Library in Denver, Colorado. A list of about 300 publications was compiled from the printout of abstracts identified through the appropriate key words. Independently, the 1980-84 issues of the water resource journals, including Land Economics, Journal of AWWA, Water Resources Research, Water Resources Bulletin, and the Journals of the ASCE were reviewed for the most recent publications.

A secondary compilation of reference listings was made by inspecting the bibliographies and citations in most recent publications and comparing them to the listing of publications discussed above.

INITIAL EXCLUSIONS

The three hundred titles included on the listing compiled during the literature search stage were individually inspected in order to determine whether they met two initial criteria for inclusion. These were:

1. whether the publication reported an empirical study of water use; and

2. whether any price-related variable was included in the data base and subsequently used as an explanatory variable in an estimated demand function.

The first criterion was used to eliminate secondary assessments of the effects of price on water use. Such publications, although often containing valuable discussion, are not intended for inclusion in the present report. This criterion allowed selection of those publications which had actual data to support their findings. The second criterion led to the exclusion of additional studies which either concentrated on the estimation of "requirements" models or which failed to report a significant relationship between water use and price. Frequently these studies suffered from study design defects such as improper specification of price variables or insufficient variance of price in the sample.

The publications which met the above criteria were further subdivided into those using sectoral water use (such as residential, commercial, institutional, industrial, and unaccounted) as the dependent variable, and those which used aggregate municipal production or sales records in the specification of the dependent variable. The price elasticity of aggregate municipal demand for water cannot be interpreted in any meaningful way because of the unknown weights of the individual sectors, each responding to price changes in a different way. While average response to price of a homogeneous group of residential users may be safely interpreted as a meaningful measure of price elasticity in residential sector, the corresponding average reponse for the aggregate of residential and industrial users will not permit such a conclusion. A significant reduction in water use by residential customers in response to price changes, accompanied by negligible changes in use by other sectors may be undetectable by measurements of total municipal water sales, especially when industrial sector strongly contributes to total municipal use. Still, the changes in revenue may be considerable especially when decreasing block tariffs are practiced. As a result, the studies of aggregate municipal water demand were given a second priority for inclusion into the pool of annotated studies, i.e., no attempt was made to include all such studies.

FORMAT OF ANNOTATIONS

Fifty-three annotations are included in the appendix to this volume. Each annotation includes three main elements: (1) bibliographical documentation; (2) the abstract in a narrative form; and (3) a summary of data base information. These parts are described in greater detail below.

The bibliographical documentation is prepared according to the format used by Water Resources Research, a leading journal in the field. The bibliographical style of this journal was also selected for previous reports prepared for the IWR because of its clarity and wide spread use (with only minor modifications) by other periodicals in the water resources discipline.

The narrative abstract includes five basic elements: (1) the brief statement describing the specific objectives, location, and time period of the study; (2) a short description of the data characteristics; (3) the results transformed by the abstractor into an explicit mathematical form such as a multivariate linear equation; (4) definition of unconventional explanatory variables and their units of measurement; and (5) a closing paragraph containing a concise statement of major findings related to price of water and, when applicable, comments on the appropriateness of statistical tools used by the authors. Items (1) and (2) are often combined into the first paragraph in order to improve the readability of the abstract.

Finally, the last part of the annotation presents specific information in the form of a checklist. The pertinent information is grouped into two categories: (1) characteristics of the study area and (2) definition of water use data base. The detailed description of each item is given in table IV-1. Each checkpoint is selected to convey information required in final comparisons and analyses of price elasticities obtained in various studies without the need to consult the original report.

CROSS-REFERENCING CATEGORIES

In order to facilitate cross-referencing of the studies which meet a specified set of data characteristics, a system of codes characterizing the important elements of each study was developed. This coding system, referred to as the Data Base Information Code, is shown in table IV-2.

Since all the abstracts were prepared as document files on the Multimate word processor, any subset of annotations (files) can be easily identified through a document search utility using the codes as key words. For example, in order to compare residential water demand equations estimated from time-series data with those estimated from cross-sectional data, the appropriate two sets of studies may be identified by specifying the codes <U14,M11> and <U14,M12>, respectively. If only studies using marginal price as explanatory variables are desired, then an additional third code <M2Pms> can be specified. The code categories in table IV-2 represent those characteristics of the data in each study which might have some bearing on the estimates of price elasticity.

Table IV-1
DATA BASE INFORMATION

Study Area Data

Location and water users: city, SMSA, state, type and number of users.

Mean summer temperature: (T), normal, in degrees F.

Mean summer precipitation: (F), normal, in inches.

Mean summer evapotranspiration: (ET), normal, in inches.

Mean summer moisture deficit: M = (ET - 0.6F), summer evapotranspiration less effective summer precipitation.

Water rates: flat rate, uniform, increasing and decreasing block, mixed.

User sector: aggregate municipal, residential single-family, residential multi-family, all residential, commercial, institutional, commercial/institutional, industrial, public, unaccounted, all uses except unaccounted, all uses except industrial.

Area character: urban, suburban, metropolitan, rural, and other.

Water Use Data

Maximum number of cases: maximum number of cases subject to statistical analysis (for pooled time series and cross sectional data equal to number of time periods times number of users).

Type of measurement: primary, if measurements made for the purpose of the study; secondary, if measurements made for other purposes.

Measurement period: month/year to month/year of data.

Dependent variable: definition of water use in the estimated model(s).

Summer season definition: calender dates of the season when dependent variable specification includes seasonal water use.

Winter season definition: as above.

Estimating technique: ordinary least squares (OLS), generalized least squares, factor analysis, autoregressive and/or lagged models, Ridge regression.

Price variable specification: a precise definition of price-related variables (e.g. real marginal price for average user in the sample in $/1000 gallons).

Special circumstances: presence of special circumstances during sampling period (droughts, conservation programs, significant rate changes).

Minimum, maximum, and mean variable values: if reported, minimum to maximum and mean values for the dependent, price-related, and other significant variables used in the analysis.

Price elasticities: estimates are reported.

Table IV-2
DATA BASE INFORMATION CODE

D(nn) = WATER USE DATA

D1(n) = TYPE OF MEASUREMENTS
- D11 = primary,(made for the purpose of the study), individual users
- D12 = secondary,(made for other purposes),individual users (water bills)
- D13 = primary,groups of users with similar characteristics (master-metered areas)
- D14 = secondary, groups of users with dissimilar characteristics
- D15 = aggregate production records
- D16 = aggregate water sales

D2(n) = IDENTIFICATION OF DEPENDENT VARIABLE:
- D21 = monthly
- D22 = summer/winter division
- D23 = seasonal/non-seasonal
- D24 = annually
- D25 = other

D3(n) = PERIOD OF MEASUREMENT
- D31 = before 1950
- D32 = 1951-1955
- D33 = 1956-1960
- D34 = 1961-1965
- D35 = 1966-1970
- D36 = 1971-1975
- D37 = 1976-1980
- D38 = 1981-1985

D4(n) = WATER RATES
- D41 = flat rate
- D42 = uniform price (commodity charge)
- D43 = decreasing block
- D44 = increasing block
- D45 = mixed rates in multi-site data
- D46 = unknown or not applicable

M(nn) = WATER USE MODELS

M1(n) = DATA SET CONFIGURATION
- M11 = time series
- M12 = cross-sectional
- M13 = pooled time series and cross-sectional
- M14 = autoregressive moving average
- M15 = other

M2(code) = PRICE VARIABLE SPECIFICATION
- M2Pau = average price for all customers of utility
- M2Pas = average price for all users in sample
- M2Pac = average price for each user in sample
- M2Pms = marginal price for average user in sample
- M2Pmc = marginal price for each user in sample
- M2Das = Nordin's bill difference for average user in sample
- M2Dac = Nordin's bill difference for each user in sample

E(nn) = ERRORS AND SPECIAL CIRCUMSTANCES

E1(n) = SPECIAL CIRCUMSTANCES DURING SAMPLING PERIOD
- E11 = drought
- E12 = other water supply emergency
- E13 = conservation programs in effect
- E14 = water use restrictions in effect
- E15 = significant rate change
- E16 = significant service area change
- E17 = not reported

Table IV-2 (continued)

U(nn) = USER AND STUDY AREA CHARACTERISTICS

U1(n) = USER SECTOR
- U11 = aggregate municipal
- U12 = residential single-family
- U13 = residential multi-family
- U14 = all residential
- U15 = commercial
- U16 = institutional
- U17 = commercial/institutional
- U18 = industrial
- U19 = public
- U110 = unaccounted
- U111 = all uses except unaccounted
- U112 = all uses except industrial

U2(n) = STUDY AREA
- U21 = urban
- U22 = suburban
- U23 = metropolitan
- U24 = rural
- U25 = other
- U26 = unknown

U3(n) = AREAL SAMPLE
- U31 = single area
- U32 = multiple sites
- U33 = other configurations

U4(n) = MEAN SUMMER PRECIPITATION
- U41 = less than 5 inches
- U42 = 5 to 10 inches
- U43 = 10 to 15 inches
- U44 = 15 to 20 inches
- U45 = greater than 20 inches
- U46 = not applicable

U5(n) = MEAN SUMMER EVAPOTRANSPIRATION
- U51 = less than 10 inches
- U52 = 10 to 15 inches
- U53 = 15 to 20 inches
- U54 = greater than 20 inches
- U55 = not applicable

U6(n) = MEAN SUMMER TEMPERATURE
- U61 = less than 60 °F
- U62 = 60 to 64 °F
- U63 = 65 to 69 °F
- U64 = 70 to 74 °F
- U65 = greater than 75 °F
- U66 = not applicable

V. DISCUSSION OF RESULTS

SUMMARY OF FINDINGS

Scope of the Literature

There are more than 50 substantial analyses of water use/price data in the open literature. The earliest known study was published in 1926 by Leonard Metcalf, a prominent consulting engineer. Metcalf, using bivariate graphical analysis of a large cross-sectional sample, noted a strong negative relationship between per capita municipal water use and price.

No further work on this subject is evident until the late 1950s, when two studies of municipal water use (Seidel and Baumann 1957; and an unpublished seminar paper by Renshaw 1958); and one study of residential water use (Fourt 1958) appeared. These studies, predating general availability of high-speed digital computers, employed simple analytical methods and investigated relatively few explanatory variables.

During the 1960s, studies of the effect of price on municipal (aggregate) water use began to appear regularly. Four contributions are analyzed in this report (Gottlieb 1963; Gardner and Schick 1964; Flack 1965; Bain et al. 1966). Interest in the residential sector began to grow rapidly after 1967, when studies by Howe and Linaweaver, Ware and North, and Conley were published. The Howe and Linaweaver study, in particular, set still-existing standards for comprehensiveness and analytical sophistication. Turnovsky's influential analysis of price elasticity for both residential and industrial sectors (1969) also appeared about this time, as did Rees's (1969) work on industrial water use.

The literature expanded markedly during the 1970s. At least 15 studies of residential sector price elasticity were published in this decade, as well as five studies of the industrial sector and the single existing analysis of price response in the commercial water use sector (Lynn 1978). Five additional studies of municipal water use appeared. Four of these (Wong 1972; Young 1973; Sewell 1974; Morgan and Smolen 1976) analyzed time-series data for the first time, creating the opportunity (not expoited by these authors) of distinguishing between short-run and long-run price reponses.

As of the date of this report (1984), the present decade gives evidence of at least as much activity as the previous one. Two studies of municipal water use (both using time-series data), eight new studies of residential water use, and two analyses of the industrial sector are already in print. Overall, the apparent quality of these studies is much improved over the standards of the 1960s (the Howe and Linaweaver study was an exception to a general lack of rigor). Furthermore, most studies published since 1980 have incorporated basic improvements in the specification of the price variable, leading to much more reliable estimates of elasticity.

Altogether, this report reviews the results of 50 studies, which can be grouped as follows:

SECTOR	NO. STUDIES
Municipal (aggregate)	13
Residential	
Winter (domestic)	6
Summer or seasonal (sprinkling)	7
Combined	27
Total	28*
Industrial	9
Commercial	1
Total	50**

*Howe and Linaweaver 1967 did not consider combined residential use.

**Turnvosky (1969) and Ben-Zvi (1980) analyzed both residential and industrial sectors.

These represent essentially all published and adequately documented studies of sectoral (i.e., residential, commercial, industrial) water use, as well as a sampling of important analyses of municipal water use.

Municipal Water Use

Table V-1 lists, in summary form, descriptions of 13 studies of municipal water use. These studies provide, altogether, 32 estimates of price elasticity, ranging from -0.02 to -1.23, using data for periods from 1920 (Metcalf 1926) to 1977 (Hansen and Narayanan 1981). Some estimates of price elasticity are significant at customary levels of confidence (e.g., 0.05), others are not significant, and still others have no significance test reported (most studies published before 1970).

Studies of sectoral elasticity, reviewed below, confirm the existence of systematic differences in price response among the various sectors of municipal water use. Since total municipal use invariably includes two or more of the major sectors, municipal price response must reflect some

TABLE V-1. AGGREGATE MUNICIPAL DEMAND--EMPIRICAL STUDIES

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
1.	Metcalf-26	-0.65 n.r.	--	--	--	--	--	--	--	DL	29	--	--	Pau	29 waterworks systems for the years 1920-1924 (calculated elasticity by Wong-72)
2.	Seidel-57	-0.12 n.r.	--	0.45	--	--	--	--	--	--	--	--	--	Pau	111 water systems from 1955 AWWA survey.
		1.00 n.r.	--	0.15	--	--	--	--	--	--	--	--	--	Pau	Elasticities calculated by Howe & Linaweaver
3.	Gottlieb-63	-1.23 n.r.	--	--	--	--	--	--	10-15	DL	19	0.67	2	Pau	Annual use in 19 Kansas towns (1952 cross-section)
		-0.67 n.r.	--	--	--	--	--	--	10-15	DL	24	0.72	2	Pau	Annual use in 24 Kansas towns (1957 cross-section)
4.	Gardner-64	-0.77	0.01	0.16	0.48	78	245	1412	14	DL	43	0.83	2	Pau	Annual per capita use in 43 water systems in northern Utah
5.	Flack-65	-0.12 n.r.	--	0.45	--	--	108	--	--	--	54	--	1	Pau	54 Western cities
		-1.00 n.r.	--	0.15	--	--	213	--	--	--	54	--	1	Pau	
6.	Bain-66	-1.10	0.17	--	0.69	38	--	421	8-15	DL	41	--	1	Pau	Average annual water use per capita in 41 California water systems

Legend: MD = moisture deficit (potential evapotranspiration less effective precipitation), inches;
f(X) = the functional form where L = linear, DL = double-logarithmic, and LPL = log partial log;
N = sample size;
R^2 = coefficient of determination;
n.r. = significance of price coefficient not reported;
-- = information not available or not reported.

For explanation of price specifications see Table IV-1 and Table IV-2.

TABLE V-1. AGGREGATE MUNICIPAL DEMAND--EMPIRICAL STUDIES (continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
7.	Wong-72	-0.02 not sig.	--	--	--	--	--	--	9	DL	11	0.82	3	Pau	Per capita average use in Chicago (1951-1961 series)
		-0.28	--	--	--	--	--	--	0	DL	11	0.57	3	Pau	Per capita use in an aggregate of suburbs of Chicago (1951-1961 series)
		-0.53	--	--	--	--	--	--	9	DL	23	0.48	2	Pau	23 Chicago Sub. >25 thousand
		-0.82	--	--	--	--	--	--	9	DL	40	0.53	2	Pau	40 suburbs, 10-25 thousand
		-0.46	--	--	--	--	--	--	9	DL	25	0.38	2	Pau	25 suburbs, 5-10 thousand
		-0.27 not sig.	--	--	--	--	--	--	9	DL	15	0.29	2	Pau	15 suburbs, <5 thousand
8.	Young-73	-0.65	0.22	0.27	0.36	236	268	326	18	L	19	0.56	2	Pas	Annual water production in Tucson, Arizona (1946-1964 time series)
		-0.60	0.22	0.27	0.36	236	268	326	18	DL	19	0.60	2	Pas	
		-0.47 not sig.	0.22	0.27	0.36	236	268	326	18	L	7	0.64	2	Pas	Annual production for 1965-1971 time series
		-0.41 not sig.	0.22	0.27	0.36	236	268	326	18	DL	7	0.60	2	Pas	
9.	Sewell-74	-0.39	0.22	0.27	0.31	142	160	180	11	DL	17	0.80	4	Pas	Average per customer use in 17 water districts in Victoria Canada for 17 years (1954-1970)
		-0.46	0.22	0.27	0.31	142	160	180	11	L	17	0.79	4	Pas	

TABLE V-1. AGGREGATE MUNICIPAL DEMAND--EMPIRICAL STUDIES (continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
10.	Morgan-76	-0.44	--	--	--	--	--	--	10-17	L	396	0.68	4	Pau	Average monthly municipal use in 33 Southern Calif. cities (12 obs. in each)
		-0.45	--	--	--	--	--	--	10-17	L	165	0.45	4	Pau	Average monthly use in Nov.-March (approx. domestic use)
		-0.43	--	--	--	--	--	--	10-17	L	231	0.63	4	Pau	Average monthly use in April-Oct. (domestic & sprinkling)
11.	Clark-77	-0.63	0.20	0.66	1.30	32	91	188	9-11	L	22	0.45	1	Pms	Average per capita demand in 22 water systems in Cincinnati, Ohio
		-0.60	0.20	0.66	1.30	32	91	188	9-11	DL	22	0.38	1	Pms	
12.	Carver-80	-0.05	0.28	--	1.55	138	--	1429	12	L	373	0.97	5	Pms	Short-run and long-run elasticity of nonseasonal (Nov.-April) demand in 13 utilities in Washington.D.C.
		-0.70	0.28	--	1.55	138	--	1429	12	L	373	0.97	5	Pms	
		-0.10 (.20)	0.28	--	1.55	95	--	409	12	L	376	0.45	6	Pms	Short-run and long-run elasticities of seasonal (May-October use less non-seasonal use) demand
		-0.11 (.20)	0.28	--	1.55	95	--	409	12	L	376	0.45	6	Pms	
13.	Hansen-81	-0.47	--	--	--	--	--	--	14	DL	14 x12	0.97	5	Pau	Average monthly per connection municipal use in Salt Lake City, Utah

weighted average of the sectoral responses. The weights, however, are unknown and vary significantly from one community to another (because of varying proportions of residential, commercial, etc., water use). Price elasticity estimates for municipal water use, therefore, are expected to display greater variation than comparable estimates for sectoral use.

In attempting to characterize available estimates, many of the municipal studies can be discounted for one or more reasons. Metcalf (1926), Seidel and Baumann (1967), and Bain et al. (1966), failed to consider any explanatory variables other than price. Because of the possibility of collinearity between price and one or more excluded variables, the regression coefficients obtained for price in these studies may not be accurate estimates of the price effect.

Most early studies did not report standard errors or the results of significance tests on the regression coefficients (Metcalf 1926; Seidel and Baumann 1957; Renshaw 1958; Gottlieb 1963; Flack 1965). These elasticity estimates must also be discounted, as nothing is known of their significance. Also, there are cases where authors state that their results are not significant (e.g., Wong's (1972) result for Chicago suburbs having 5,000 population or less).

Finally, all but two of the studies utilized some measure of average price as the explanatory variable. Because of the complexity of water utility rate schedules and, perhaps, the time lags inherent in the billing process, it is not clear that average price is inferior to marginal price as an estimator of customer perception of price, economic theory notwithstanding. Average price has the benefit of capturing at least some of the effect on discretionary income of nonprice change in the rate structure. Still, most analysts favor marginal price.

Also, in the case of declining-block rates, where price is itself negatively correlated to quantity demanded, the estimated elasticity is likely to be more elastic than the true price response. (Increasing-block rates would produce an estimate less elastic than actual.)

Excluding studies which examine only price as an explanatory variable and those which do not report significance or those reported as insignificant by the author, and considering only studies using average price, the estimates of the price elasticity of municipal water demand include:

AVERAGE PRICE STUDIES

Cross-Sectional Data	
Gardner and Schick (1964)	-0.77
Wong (1972)	-0.53
	-0.82
	-0.46

Time-Series or Pooled Data	
Young (1973)	-0.65 -0.60
Wong (1972)	-0.28
Sewell and Roueche (1974)	-0.39 -0.46
Morgan and Smolen (1976)	-0.44
(winter period)	-0.45
(summer period)	-0.43
Hansen and Narayanan (1981)	-0.47

Results for the cross-sectional studies can be seen to fall in the range -0.46 to -0.82; the extremes pertain to groups of suburban communities in the Chicago area. These results apparently correspond to long-run elasticities. The time-series and pooled data studies listed here, on the other hand, made no attempt to distinguish between long-run and short-run response (no dynamic models estimated). If it is assumed that the results are biased in the direction of estimating the short-run response, then the generally more inelastic results (range: -0.28 to -0.65) seem plausible. Also, the Young study was later critized by Carver (1980) for improperly excluding seven years of data. Carver recalculated the elasticity at -0.20, a value more consistent with presumed short-run response.

Two of the municipal studies used marginal price as an explanatory variable; the results are summarized below:

MARGINAL PRICE STUDIES

Cross-Sectional Data	
Clark and Goddard (1977)	-0.63 -0.60
Time-Series or Pooled Data--Long Run	
Carver and Boland (1980)	
Winter period	-0.70
Time-Series or Pooled Data--Short Run	
Carver and Boland (1980)	
Winter period	-0.05

These studies suggest that long-run elasticity for municipal demand is in the -0.60 to -0.70 range, and that short-run elasticity may be very small. The first result is fully consistent with the results of the studies of response to average price, while the second reveals greater inelasticity than observed by other investigators. It should be noted, however, that only one study of municipal demand specifically estimated short-run elasticity, and that result pertains only to winter period use. Carver and Boland also studied summer season water use but obtained insignificant results.

Residential Water Use

Studies of residential water use can be placed into two general categories: (1) those that address average annual or monthly uses, and (2) those that deal with seasonality by separating use into summer and winter periods or into seasonal and nonseasonal components. There are 27 studies in the first category, ranging from Fourt's (1958) unpublished analysis to a recent contribution by Jones and Morris (1984). The second group include six studies of winter (nonseasonal) use, five studies of seasonal (sprinkling) uses, and two studies of summer season use. All except one (Howe and Linaweaver 1967) of the studies in the second group are also in the first group, so that the total number of residential studies is 28.

Average Annual and Monthly Residential Use

Table V-2 summarizes studies of average annual and monthly residential water use. The 27 studies provide 60 individual estimates of price elasticity. In some cases, no test of the statistical significance of these estimates is provided, in others the estimate is stated by the author to be insignificant. Most studies in this group appear to have considered explanatory variables other than price.

In order to compare the results, those estimates stated (by the author) to be without statistical significance and those with no indication of a test for significance are excluded, as well as results of studies which apparently did not consider explanatory variables other than price. The elasticity estimates for studies based on average price follow:

AVERAGE PRICE STUDIES

Cross-Sectional Data	
Ware and North (1967)	-0.67 -0.61
Turnovsky (1969)	-0.28 -0.25

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
1.	Fourt-58	-0.39	--	--	--	--	--	--	--	DL	34	0.68	3	Pms	34 urban systems from 1955 AWWA survey
2.	Conley-67	-1.02	--	--	--	--	--	--	9-15	DL	24	0.53	3	Pau	Residential per capita water use in 24 Southern California communities
		-1.09	--	--	--	--	--	--	9-15	DL	24	0.52	1	Pau	
3.	Hittman-70	-0.44	0	0.42	0.96	114	245	496	--	DL	27	0.59	3	Pms	27 cities from 1960 AWWA survey and mail questionnaire
4.	Grima-72	-0.93	--	0.45	--	--	143	--	7-9	DL	91	0.56	4	Pms	91 households in Toronto metro area
5.	Morgan-74	-0.49	--	--	--	--	--	--	11	L	31	0.93	8	Binary	Average elasticity for 35 households in Santa Barbara, CA
6.	Hogarty-75	-0.86	--	--	--	--	--	--	8	--	120 x9	--	--	Pmc	Short-run (3 months) and long-run (1 year) ave. elasticities for 120 households in Blacksburg, Virginia
		-0.56	--	--	--	--	--	--	8	--	120 x9	--	--	Pmc	
7.	Gardner-77	-0.24	0.15	0.85	1.95	39	79	228	7-9	L	75	0.28	4	Pms	75 cities in Minnesota from a mail survey
		-0.15	0.15	0.85	1.95	39	79	228	7-9	DL	75	0.36	3	Pms	
8.	Gibbs-78	-0.51	0	0.28	0.60	11	355	3733	2	LPL	1412	0.60	8	Pmc	Quarterly water use by 355 households in Miami, Fla. (four quarters)
9.	Camp-78	-0.24	0.45	0.93	0.165	115	197	326	13	L	288	0.60	13	Pms	288 residences in 10 Northern Mississippi cities
		-0.31	0.45	0.93	0.165	115	197	326	13	LPL	288	0.58	8	Pms	

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES (Continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
10.	Danielson-79	-0.27	--	--	--	--	206	--	7	DL	261 x68	--	5	Pmc	261 households with 68 observations on each, Raleigh, North Carolina
11.	Cassuto-79	-0.30	--	--	--	--	--	--	9	L	246 x72	--	11	Pms	Monthly residential use in 246 census tracts for 72 months in Oakland, CA
		-0.21	--	--	--	--	--	--	9	L	246 x72	--	11	Pms	
12.	Billings-80	-0.49 (.25)	0.21	0.26	0.42	--	443	--	18	L	45	0.82	4	Pms,Dms	45 observations on average residential use in Tucson, Arizona (monthly billing periods)
		-0.27 (.10)	0.21	0.26	0.42	--	443	--	18	DL	45	0.83	4	Pms,Dms	
13.	Billings-82	-0.66	0.21	0.26	0.42	--	443	--	18	L	45	0.82	4	Pms,Dms	Reestimated from Billings-80 data with respecified P and D variables
		-0.56	0.21	0.26	0.42	--	443	--	18	DL	45	0.81	4	Pms,Dms	
14.	Agthe-80	-0.36 (.10)	0.21	0.26	0.42	--	443	--	18	L	45	0.83	5	Pms,Dms	Reestimated from Billings-80 data, interpreted as short-run elasticities
		-0.18 (.15)	0.21	0.26	0.42	--	443	--	18	DL	45	0.86	5	Pms,Dms	
		-0.50 (.10)	0.21	0.26	0.42	--	443	--	18	L	45	0.80	4	Pms,Dms	Estimates interpreted as long-run elasticities
		-0.27 (.10)	0.21	-.26	0.42	--	443	--	18	DL	45	0.81	4	Pms,Dms	
15.	Ben-Zvi-80	-0.73	--	0.79	--	--	344	--	12-16	DL	12	0.88	5	Pms	Non-industrial use per customer in 12 communities in Red River Basin

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES (Continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
16.	Morris-80	-0.39	--	0.69	--	--	466	--	9-10	L	21	0.65	3	Pms	384 households in 21 Denver metro areas
		-0.16	--	0.63	--	--	424	--	9-10	L	384	0.37	11	Pmc	
17.	Jones-84	-0.07 not sig.	--	--	--	--	--	--	9-10	L	326	0.26	4	Pms,Dms	Reestimated from Morris-80 data (see above), elasticity does include D variable effects
		-0.18	--	--	--	--	--	--	9-10	LPL	326	0.28	4	Pms,Dms	
		-0.21	--	--	--	--	--	--	9-10	DL	326	0.25	4	Pms,Dms	
18.	Ware-67	-0.67	0.20	0.91	2.43	79	217	410	9	L	14	0.69	2	Pau	Annual use in 634 households in 14 Georgia communities
		-0.61	0.20	0.91	2.43	79	217	410	9	DL	14	0.68	2	Pau	
19.	Turnovsky-69	-0.28	--	--	--	--	--	--	9-11	L	14	0.86	3	Pau	"Planned" annual per capita non-industrial use in 19 Massachusetts towns
		-0.25	--	--	--	--	--	--	9-11	L	14	0.77	3	Pau	Elasticities for 1962 and 1965 cross-sections, respectively
20.	Primeaux-73	-0.26	--	0.86	--	--	75	--	11-14	L	402	0.56	11	Pau	402 households in 14 rural Northern Mississippi cities
		-0.37	--	0.86	--	--	75	--	11-14	L	402	0.47	4	Pau	
		-0.45	--	0.86	--	--	75	--	11-14	DL	402	0.52	4	Pau	

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES (Continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
21.	Pope-75	-0.33 n.r.	--	--	--	--	--	--	6-11	--	1464	--	--	Pac	Arc elasticities for the first and the second year after price increase for 1464 households in 4 So. Carolina communities
		-0.14 n.r.	--	--	--	--	--	--	6-11	--	1464	--	--	Pac	
22.	Gibbs-78	-0.62	0.20	0.58	7.50	11	355	3733	2	LPL	1412	0.46	7	Pac	Quarterly use in 355 households in Miami, Florida
23.	Grunewald-78	-0.92	0.27	2.27	14.49	8	154	1429	9-11	DL	150	0.67	2	Pau	Annual residential use in 150 rural water districts in Kentucky
24.	Foster-79	-0.47	0.09	0.49	1.37	97	223	1020	--	LPL	218	0.54	4	Pau	Average annual use in 218 cities (1960 AWWA Survey)
		-0.52 -0.65	--	--	--	--	--	--	--	LPL	35	0.74	4	Pau	New England and North Atlantic region (1960 & 1970 data, respectively)
		-0.30 -0.33	--	--	--	--	--	--	--	LPL	97	0.74	4	Pau	Midwest
		-0.38 -0.60	--	--	--	--	--	--	--	LPL	42	0.74	4	Pau	South
		-0.58 -0.60	--	--	--	--	--	--	--	LPL	12	0.74	4	Pau	Plains and Rocky Mountains
		-0.36 -0.69	--	--	--	--	--	--	--	LPL	18	0.74	4	Pau	Southwest
		-0.69 -0.68	--	--	--	--	--	--	--	LPL	14	0.74	4	Pau	Northern California and Pacific Northwest

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES (Continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
25.	Male-79	-0.20	0.22	0.73	4.86	36	271	838	5-9	L	56	0.50	4	Pau	Annual sales to metered residential customers in 56 utilities in 6 North Eastern states
		-0.37	0.22	0.73	4.86	36	271	838	5-9	LPL	56	0.69	4	Pau	
		-0.68	0.22	0.73	4.86	36	271	838	5-9	DL	56	0.73	4	Pau	
26.	Jones-84	-0.18	--	0.60	--	--	450	--	9-10	L	326	0.26	3	Pas	Reestimated from Morris-80 data using average price specification
		-0.29	--	0.60	--	--	450	--	9-10	LPL	326	0.23	3	Pas	
		-0.34	--	0.60	--	--	450	--	9-10	DL	326	0.23	3	Pas	
27.	Hanke-82	-0.15	--	--	--	--	--	--	--	L	16x4	0.26	6	Pmc	Sales to 69 single-family residences during 14 semi-annual periods in Malmo, Sweden

Primeaux and Hollman (1973)	-0.26 -0.37 -0.45
Grunewald et al. (1978)	-0.92
Foster and Beattie (1979)	-0.47 -0.52 -0.65 -0.30 -0.33 -0.38 -0.60 -0.58 -0.60 -0.36 -0.69 -0.69 -0.68
Male et al. (1979)	-0.20 -0.37 -0.68
Jones and Morris (1984)	-0.18 -0.29 -0.34
<u>Time-Series or Pooled Data</u>	
Gibbs (1978)	-0.62

These studies all employ some measure of average price as the estimator of the price variable, and all except the Gibbs (1978) study are based on cross-sectional data. Cross-sectional analyses are expected to yield estimates of price elasticity which approximate a long-run response. Pooled times-series/cross-sectional data bases, on the other hand, can support estimates of both long-run and short-run elasticity (provided a suitable dynamic model is used), as well as seasonal variation in price response. The single pooled data study utilizing average price (Gibbs 1978) did not attempt an estimate of short-run elasticity. All average price study results reported here, therefore, can be viewed as estimates of the long-run price elasticity of average annual water use.

The results of these studies range from -0.18 to -0.92. The most elastic estimate derives from the study by Grunewald et al. (1978) of 150 rural areas in Kentucky. The investigators in this case were unable to find significant relationships between water use and such variables as household size, housing value, and income; they obtained the elasticity from a bivariate regression (water use on average price). The possibility of a biased result seems substantial.

None of the studies in this group reported uniform commodity charges: all had either declining-block rates, mixed rate forms, or no information was provided. It can be hypothesized that, in the case of declining-block rates, elasticity estimates are biased (in the direction of greater elasticity). The degree of bias varies, however, with the rate designs' degree of deviation from uniform charges. The Jones and Morris study (1984), for example, is based on data from a region with both declining-block and increasing-block rates (Denver). It is not surprising, then, that the results are among the most inelastic estimates (ranging from -0.18 to -0.34, depending on the model specification).

These results are also in good agreement with those of Turnovsky (1969), Primeaux and Hollman (1973), and Male et al. (1979), excluding the double-log model. It seems likely that the unbiased elasticity of annual water use in the residential sector with respect to average price is in the vicinity of -0.20 to -0.40.

Residential water use studies which employ some measure of marginal price as an explanatory variable are as follows:

MARGINAL PRICE STUDIES

<u>Cross-Sectional Data</u>	
Fourt (1958)	-0.39
Hittman Associates (1970)	-0.44
Grima (1972)	-0.93
Gardner (1977)	-0.24 -0.15
Camp (1978)	-0.24 -0.31
Ben-Zvi (1980)	-0.73
Morris and Jones (1980)	-0.39 -0.16
Jones and Morris (1984)	-0.07 -0.18 -0.21
<u>Time-Series or Pooled Data</u>	
Gibbs (1978)	-0.51

Danielson (1979)	-0.27
Billings and Agthe (1980)	-0.49 -0.27
Agthe and Billings (1980)	
Short run	-0.18 to -0.36
Long run	-0.27 to -0.50
Billings (1982)	-0.66 -0.56
Hanke and de Mare (1982)	-0.15

Except for the Grima (1972) and Ben-Zvi (1980) studies, the cross-sectional results show quite inelastic demand for residential water, all falling within the range -0.07 to -0.44. The Ben-Zvi study is based on a small sample (data for 20 communities of widely varying size, each community comprising one observation) of users, all of whom face delining-block rate designs. Also, in spite of its characterization as a "residential" study, the text suggests that water use data may include commercial and institutional use (it may be "nonindustrial" rather than residential). These factors could explain the discrepancy between Ben-Zvi's results and those of similar studies performed elsewhere. On the other hand, there is no obvious explanation for the differences between Grima's results and those of other investigators, other than differing price response.

Of the six time-series or pooled data studies, five utilized static models, yielding estimates of long-run price elasticity (Agthe and Billings [1980] used a Koyck transform dynamic model). The static models provide estimates of long-run price elasticity in the range of -0.15 to -0.66. The long-run results from the Agthe and Billings dynamic model (-0.27 to -0.50) also fall within this range. The most elastic estimates are due to Billings (1982), who employed a marginal cost obtained from a regression equation (he regressed the total water bill on water use) rather than actual rate schedules. It is not known what type of bias, if any, this procedure might create.

Billings and Agthe (1980), Agthe and Billings (1980), and Billings (1982) all included a bill difference variable in their models and all obtained significant negative coefficients for this term. None of the reports indicate the relationship between the value of the bill difference term and marginal price; the elasticity calculations reported do not take such a relationship into account. Where bill difference is negatively correlated with marginal price (because of fixed charges or a declining-block rate form), proper calculation of elasticity with respect to marginal price will produce a more inelastic result than when the bill difference is ignored.

Based on these marginal price studies, the true long-run elasticity of annual residential water demand is apparently in the vicinity of the range -0.20 to -0.40, the same range deduced from the average price studies described above.

Agthe and Billings (1980) also provide estimates of short-run elasticity which are slightly more inelastic than the corresponding long-run estmates.

Winter (Nonseasonal) Residential Use

Table V-3 lists information describing studies of residential winter season water use. Five of these studies report significant price elasticities; all five utilize marginal price as the price variable. The elasticities are:

MARGINAL PRICE STUDIES

Cross-Sectional Data	
Howe and Linaweaver (1967)	-0.23
Grima (1972)	-0.75
Ben-Zvi (1980)	-0.79
Howe (1982)	-0.06
Time-Series and Pooled Data	
Danielson (1979)	-0.30

Once again, the Grima and Ben-Zvi studies produce much more elastic estimates than obtained elsewhere. Possible biases in the Ben-Zvi estimate are as described above; no biases have been identified for the Grima study. The Danielson estimate is obtained from a static model and refers, therefore, to the long-run response. It is consistent with the Howe and Linaweaver result.

The Howe and Linaweaver (1967) results have been long regarded as the most reliable available estimates of residential price elasticity. Their study used primary data obtained from a carefully designed national sample, and the data analysis was comprehensive and thoroughly documented. Howe (1982) reanalyzed this data set, adding a bill difference variable to the explanatory factors previously considered. The dependence of the bill difference on marginal price was accounted for in calculating price elasticity, giving an estimate substantially more inelastic than previously available. All available evidence points to Howe's result as the most reliable estimate of residential winter (nonseasonal) price elasticity.

Gallagher and Robinson (1977) report results of a pricing experiment in Australia which are consistent with the empirical results shown here. They estimate winter residential price elasticity at -0.24, based on hypothetical prices, using no bill difference term.

TABLE V-3. RESIDENTIAL DEMAND--DOMESTIC USE (WINTER, NONSEASONAL, IN-HOUSE)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
1.	Howe-67	-0.23	--	0.40	--	--	226	--	11	DL	21	0.72	2	Pms	21 residential areas (East and West)
2.	Howe-82	-0.06	--	0.40	--	--	261	--	11	L	21	--	3	Pms,Dms	Reestimated from Howe-67 data with D-variable, elasticity includes D-effects
3.	Morris-80'	-0.09 not sig.	--	0.62	--	--	221	--	9-10	L	21	0.66	3	Pms	Average data for individual households in 21 Denver metro areas
4.	Danielson-79	-0.30	--	--	--	--	219	--	7	DL	--	--	5	Pms	Average use during Nov.-April (261 households in Raleigh, N. Carolina)
5.	Ben-Zvi-80	-0.79	--	0.79	--	--	308	--	12-16	DL	20	0.81	3	Pms	Lowest monthly non-industrial use in 20 communities in Red River Basin
6.	Grima-72	-0.75	--	0.45	--	--	128	--	7-9	DL	91	0.49	4	Pmc	Average winter use during Nov.-March for 91 households in Toronto area

Summer Residential Use

Table V-4 shows studies of summer and seasonal residential water use. Two of these contain significant estimates of the price elasticity of summer residential water use; both are cross-sectional and based on marginal price:

MARGINAL PRICE STUDIES

Cross-Sectional Data	
Grima (1972)	-1.07
Howe (1982) Eastern U.S. only	-0.57

The Howe study uses the data set from the 1967 Howe and Linaweaver study, and incorporates a bill difference variable. The relationship between marginal price and the bill difference variable is accounted for in calculating price elasticity. The result is considered more representative than Grima's earlier estimate, which is based on a simpler price specification. Howe attempted a similar calculation for communities in the western U.S., but the result (-0.43) was not significant.

Seasonal (Sprinkling) Residential Use

Four studies shown in table V-4 consider seasonal use, defined as the excess of annual use over the nonseasonal component (estimated from winter use). Following Howe and Linaweaver's (1967) definition, seasonal use is assumed to consist primarily of water used for weather-related purposes, such as irrigating lawns and gardens. All available studies used marginal price as the price variable:

MARGINAL PRICE STUDIES

Cross-Sectional Data	
Howe and Linaweaver (1967)	
Eastern U.S.	-1.57
Western U.S.	-0.73
Ben-Zvi (1980)	-0.82

TABLE V-4. RESIDENTIAL DEMAND--SEASONAL (SPRINKLING) AND SUMMER USES

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
1.	Howe-67	-1.57	0.17	0.40	1.02	37	226	481	10	DL	11	0.93	3	Pms	Average day sprinkling demand in 11 eastern areas (Des Moines, Fort Worth, Little Rock, Washington, D.C., Baltimore, Philadelphia)
		-0.73	0.24	0.36	0.61	167	387	780	12	DL	10	0.67	2	Pms	Average day sprinkling in 10 western areas (Oakland, Los Angeles, San Diego)
2.	Grima-72	-1.07	--	0.45	--	--	158	--	7-9	DL	91	0.55	4	Pms	Summer use (May-August) in 91 households in Toronto metro area
3.	Danielson-79	-1.38	--	--	--	--	27	--	7	DL	--	--	4	Pms	Sprinkling use (May-Oct. use less Nov.-April use) in 267 households in Raleigh, North Carolina
4.	Ben-Zvi-80	-0.82	--	0.79	--	--	141	--	12-16	DL	12	0.38	4	Pms	Sprinkling use (Ave. use in June-Sept., less domestic use, in 12 towns in Red River Basin)
5.	Morris-80	-0.73	--	1.13	--	--	240	--	9-10	L	21	0.64	3	Pms	Sprinkling use per household (ave. use in March-October, less domestic) in 889 houses in 21 districts in Denver metro area
6.	Howe-82	-0.57	--	0.41	--	--	415	--	10	L	11	--	4	Pms,Dms	Summer use (domestic & sprinkling) in 11 eastern areas
		-0.43 not sig.	--	0.36	--	--	658	--	12	L	10	0.84	4	Pms,Dms	Summer use in 10 western areas (reestimated from Howe-67 data)
7.	Morgan-76	-0.55	--	--	--	--	--	--	10-17	L	165	0.54	4	Pau	Sprinkling demand (dry period usage minus minimum wet period usage)

Morris and Jones (1980)	-0.73
Time-Series and Pooled Data	
Danielson (1979)	-1.38

Since the Ben-Zvi and Morris and Jones studies used data from the western U.S. (Southwest and Denver, respectively), they are consistent with Howe and Linaweaver's estimate for elasticity in that region. Similarly, Danielson, who used data from North Carolina, provides an estimate which is consistent with Howe and Linaweaver's result for the eastern U.S. None of these studies used a bill difference variable (bill difference cannot be calculated for a component of water use). Based on experience with application of bill difference variables to summer season use, it seems likely that the results shown are biased upward (too elastic).

Industrial Water Use

Table V-5 describes, in summary form, nine studies of industrial water use. While all of these studies attempted to include some type of price variable, not all provided useful estimates of price elasticity. In particular, DeRooy (1974), Ben-Zvi (1980), and Zeigler and Bell (1984) analyzed self-supplied industrial water use and used the average cost (or, in the case of Zeigler and Bell, both average and marginal cost) of water to the firm as the price variable. "Price"-quantity observations, expected to be points on the demand curve for water, are more likely, in this case, to be points on the supply curve. Also, Rees (1969) estimated some models containing a term described as "price paid for all purchased supplies"; other models contain a measure of the price of metered water. It is not clear whether the former term is a measure of price or cost.

Because of the price-cost problem, only those studies which address the use of municipally-supplied water yield useful estimates of price elasticity. Six of the studies contain such results, as listed below. In most cases, it is not possible to determine whether average or marginal price was used.

MARGINAL AND/OR AVERAGE PRICE STUDIES

Cross-Sectional Data	
Rees (1969)	
Chemical firms	-0.96
Food firms	-3.29 to -6.71
Beverage firms	-1.30 to -4.10
Nonmetallic mineral firms	-2.50

TABLE V-5. INDUSTRIAL DEMAND FOR WATER--EMPIRICAL STUDIES

No. Study Code	Industry or Purpose of usage	Price Elasticity/Significance	Range of Price Elasticities	f(X)	N	R^2	Variables in the Equation	Remarks
1. Rees-69	Aggregate industrial	+0.81 n.r.	--	DL	166	0.35	E,t,P_p	253 manufacturers in S.E. England
	Chemical firms	- 0.96 n.r.	--	DL	50	0.37	Pr,Qs	E = employment; T = tonnage of raw materials used by the firm
	Food firms	--	-3.29 to -6.71	LPL	15	0.60	Pr	
	Drink firms	--	-1.30 to -4.10	LPL	8	0.36	Pr	P_p = price paid for all purchased water
	Paper and paper products	-1.95 n.r.	-1.44 to -2.88	DL	22	0.55	Pp, Qs	Pr = price paid for metered purchases
	Plastic and rubber	not significant e.g. (positive price coeff.)						
	Non-metallic mineral firms	-2.50 n.r.	--	L	13	0.31	Pr	Q_s = self-supplied water
2. Ethridge-70	Poultry processing firms	-0.43 (for Pmt+Pss) -0.63 (for P_{wts})		LPL	26	0.55	Pmt+0.5 Pss and P_{wts}	27 obs. on 5 poultry proc plants Pmt = sewer surcharge on BOD_5 Pss = sewer surcharge on SS P_{wts} = marginal price paid for sewer and water

TABLE V-5. INDUSTRIAL DEMAND FOR WATER--EMPIRICAL STUDIES (Continued)

No. Study Code	Industry or Purpose of usage	Price Elasticity/Significance	Range of Price Elasticities	f(X)	N	R^2	Variables in the Equation	Remarks
3. Turnovsky-69	Aggregate industrial purchases from municipalities	-0.50	-0.47 to -0.84	L	16	0.92	Pau, S^2	Industrial sales in 19 Massachusetts towns
		-0.63		L	18	0.89		Pau = average price; S^2 = supply variance
4. Ridge-72	Brewery--SIC 2082	-0.30		L	12	0.64	Pmc, X_1	90 plants in 4 SIC categories
	Fluid Milk-SIC 2026	-0.60		L	10	0.84	Pmc, X_1,E	Pmc = marginal price
	Poultry Process.--SIC 2015	-0.80 not sig.		L	10	0.59	Pmc,X_1,E	X_1 = plant size; E = employment
5. Elliot-72	Aggregate industrial purchases (in gpd per $1000 value added in manufacturing)	-0.70 (for Pms)						198 obs. for 34 cities in the U.S.
		-0.61 (for surcharge)		L	183	0.32	Pms, S,L_p and V	Pms = marginal price; S = sewer surcharge; Lp = price of labor; V = % value added by SIC 20

TABLE V-5. INDUSTRIAL DEMAND FOR WATER--EMPIRICAL STUDIES (Continued)

No.	Study Code	Industry or Purpose of usage	Price Elasticity/Significance	Range of Price Elasticities	f(X)	N	R^2	Variables in the Equation	Remarks
6.	DeRooy-74	Cooling water	-0.89 (for unit cost)		LPL	28	0.81	X_t, P_u, T	30 chemical plants in northern New Jersey
		Processing water	-0.36 (for unit cost)		LPL	23	--	X_t, P_u, T	X_t = value of output
		Steam generation water	-0.48 (for unit cost)		LPL	24	--	X_t, P_u, T	P_u = total unit cost of water
		Sanitation water	Not significant		L	18	0.92	E	T = technol. index E = employment
7.	Grebstein-79	Aggregate industrial		-0.33 to -0.80				K,L,W	All SIC 2-digit industries in the U.S. K = capital L = labor W = water input
8.	Ben-Zvi-80	Food industry--SIC 20	-2.42		DL	24	0.84	P_w,X	84 industrial plants in Red River Basin
		Lumber--SIC 24	-0.56 not sig.		DL	6	0.98	P_w,X	P_w = ave. purchase price plus treatment cost
		Paper--SIC 26	-0.56		DL	14	0.66	P_w,X	X = annual sales of the plant
		Chemicals--SIC 28	-1.47		DL	18	0.69	P_w,X	
		Petroleum--SIC 29	-0.15		DL	12	0.95	P_w,X	
		Stone and Clay	-1.13		DL	10	0.92	P_w,X	

TABLE V-5. INDUSTRIAL DEMAND FOR WATER--EMPIRICAL STUDIES (Continued)

No.	Study Code	Industry or Purpose of usage	Price Elasticity/Significance	Range of Price Elasticities	f(X)	N	R^2	Variables in the Equation	Remarks
9.	Ziegler-84	Self-supplied water	-0.98		LPL	23	0.76	Pac, X_1, and X_2	23 high-volume water using paper and chemical plants Pac = average unit cost of water X_1,S_2 = dummy variables

Turnovsky (1969)	
Aggregate industrial, 1962 data	-0.51
Aggregate industrial, 1965 data	-0.63
Elliot and Seagraves (1972)	
Aggregate industrial	-0.60
Ridge (1972)	
Breweries (SIC 2082)	-0.30
Fluid milk producers (SIC 2026)	-0.60
Poultry processing (SIC 2015)	-0.80
Grebstein and Field (1979)	
Aggregate industrial	-0.80
Time-Series and Pooled Data	
Ethridge (1970)	
Poultry processing	-0.63

None of the studies included here experimented with the price specification, or considered bill difference variables. The Ethridge study used pooled data but did not employ a dynamic model. The elasticity estimate, therefore, applies to the long-run, and is comparable to the similar estimate of Ridge (-0.63 vs. -0.80). The Rees results, obtained for Southeast England, are notable for the high level of elasticity found. This may be the result of collinearity between price and other omitted variables (the models used only price and total water intake to explain municipal water withdrawal).

It appears, on the basis of this evidence, that industrial water demand is, in general, more elastic than residential demand and varies markedly from one industrial sector to another. The best available estimates of the elasticity of aggregate industrial water demand (the municipally supplied fraction only) are in the range -0.50 to -0.80.

Commercial Water Use

As shown on table V-6, only one study has attempted to estimate the price elasticity of commercial water use (Lynn et al. 1978). This study, which developed six separate models (for five categories of use in the Miami, Florida, area), resulted in significant estimates of price elasticity in four cases, as follows:

TABLE V-6. COMMERCIAL DEMAND FOR WATER--EMPIRICAL STUDIES

No.	Study Code	Type of Establishment	Price Elasticity/Significance	f(X)	N	R^2	Variables in equation	Remarks
1.	Lynne-78	Department Stores	-1.33	LPL	20	0.78	Pms, X_1, X_2	Pms = marginal price for average user in sample X_1 = store area
		Grogery and Supermarket	-0.76	LPL	19	0.73	Pms, S_1, D_1	X_2 = area of restaurant D_1 = dummy variable for presence of kitchen
		Motels and Hotels	-0.24	LPL	40	0.95	Pms, NR, P_2,DB	NR = number of rooms for rent
			-0.12	LPL	93	0.94	Pms,NR, P_2	P_2 = weighted average of maximum BH = Prices for rooms
		Eating and Drinking	-0.174 (0.20)	LPL	24	0.25	Pms, DH, BH	DB = dining room plus bar area
		Other commercial	-0.48 (0.20)	LPL	32	0.35	Pms, X_1, X_3, D_2	DH = dining room area BH = bar room area D_2 = dummy variable for presence of water cooled air conditioning

AVERAGE COST STUDIES

Cross-Sectional Data	
Lynn et al., (1978)	
Department stores	-1.33
Groceries and supermarkets	-0.76
Hotels, motels (primary data)	-0.24
(secondary data)	-0.12

No experimentation with the price variable specification is evident, and no bill difference variable was considered. The results also include an estimate of elasticity for the "other commercial" category, found to be -0.48 but only significant at the 0.20 level. Taken together, these estimates suggest that the commercial sector may be more elastic than the residential sector, but that elasticity may vary substantially from one category of user to another.

CRITIQUE

Explanatory Variables

One of the most important opportunities for bias in price elasticity studies (after sample selection and data measurement) lies in the choice of the explanatory variables to be considered in the regression model. Price is commonly collinear with other variables, and the omission of those variables may bias the price coefficient.

For example, price is usually lower in larger communities, which also contain relatively greater numbers of multi-unit residential buildings. If the dependent variable is per capita water use, it would be expected to be higher if a larger fraction of the population live in smaller household units, and it would also be higher if the price were lower. Omission of explanatory variables which describe household size or fraction multi-unit housing would result in both effects being reflected in the price coefficient, leading to an overestimate of the price elasticity.

Another example can be proposed which is relevant to time-series data sets. If real price has fallen over time (as it has in most locations prior to the late 1970s), but affluence has risen, both trends would be expected to reduce water use. The omission of any satisfactory proxy for affluence would again, force the price coefficient to reflect the combined effect, overestimating price elasticity.

One variable omitted by all but the most recent studies is the bill difference term, also known as a Nordin variable. This factor captures some of the income effect associated with various rate structures. Customers served under decreasing-block rate structures will face positive bill differences. If those same customers are compared to others who pay a lower marginal price under an unblocked structure (without a minimum or service charge), the decreasing-block customers will be seen to use less water for two reasons: (1) they face a higher marginal price; and (2) they also pay large inframarginal charges, reducing discretionary income. Omitting the bill difference variable from the regression would cause the price coefficient to reflect both effects, overestimating price elasticity.

Review of the studies analyzed in this report indicates that most models are very sparsely specified, that is, many relevant variables are omitted. Where the omitted variables are correlated with water use and collinear with price, or when they include a bill difference term (and block-type rate structures are in use), bias in the price coefficient is likely to result. In many plausible cases, such as those described above, the direction of the bias is upward: the estimate is more elastic than if the model were correctly specified.

Price Variable Specification

Another common source of bias concerns the specification of the price variable. Most early studies measured price as the average revenue contributed by all utility customers (average price). Later, efforts were made to measure average revenue contributed by those users included in the data sample, or to measure the marginal price faced by those users. In the case of block-type rate schedules, marginal price sometimes represents the price faced at the margin by the "average" user, sometimes it is the average of all marginal prices in effect throughout the sample, and sometimes it is the incremental price for a block of usage in a "typical" range.

Economists have long recognized both average and marginal price specifications, taken by themselves, to be inadequate. While rational users can be presumed to base their usage decisions on marginal price, it is not clear that the information typically available facilitates this behavior. Furthermore, complex utility rate schedules include income transfers which may affect use, and which are not captured by conventional income variable specifications.

The bill difference variable, described in chapter III, when combined with a marginal price variable, incorporates at least some of the complexity of utility rate schedules. Bill difference was first introduced to residential water use studies by Billings and Agthe in 1980, and most residential studies published since then have incorporated it. However, only one study (Howe 1982) explicitly calculates price elasticity as a function of both marginal price and bill difference coefficients. The bill difference variable has not, as yet, been applied to studies of nonresidential water use.

Level of Aggregation

There are few truly homogeneous groups of water users. Most user classes or categories are comprised of a number of very different water users, each using water in a number of very different ways. Still, systematic differences in price response can be observed among user classes. When price response is measured at too high a level of aggregation, these differences are submerged in the data, and the result is an elasticity which is, at best, a weighted average of the component elasticities.

Regression theory requires that the variance in the dependent variable be unrelated to the values of the explanatory variables (the "constant variance" or "homoscedasticity" assumption). It is unlikely that this assumption is met when the explanatory variables include weather terms: since some water uses are weather dependent, the variance of water use almost certainly changes with the weather. Data aggregated over time are, therefore, likely to violate the assumption (to be heteroscedastic); the longer the time and the greater the changes in weather, the greater the range of variance. Heteroscedasticity can be minimized, but not eliminated, by analyzing seasonal, rather than annual water use.

The best example of an aggregation problem is the practice of analyzing average annual municipal water use. Neglecting statistical problems arising from heteroscedasticity, the elasticity which results is a weighted average of residential, commercial, institutional, industrial, etc., elasticities, as well as a weighted average of summer and winter elasticities for each of the classes. As the weights vary from community to community (because of different proportions of users in each class or because of different weather patterns), the aggregate elasticity varies as well. Such results may be useful in the community for which they are derived, but they are not usually transferable to other communities.

Since studies have shown relatively large differences between elasticities for residential winter use and residential summer use, the practice of analyzing average residential use without regard to season conceals the true components of price response. The same may be true for other sectors of water use, but no studies are yet available which conclusively demonstrate significant seasonal differences.

The most generally applicable estimates of price elasticity, therefore, are those which apply to the smallest and most homogeneous classes of water use. In the case of residential use, these would include estimates of winter (nonseasonal) and summer (or, alternatively, seasonal) elasticities. In the case of industrial or commercial water use, estimates of elasticity for specific categories (e.g., poultry processing, department stores, etc.) are preferable to estimates for the class as a whole. Using higher levels of aggregation introduces study area-specific variation into the estimates, producing a broader range of results while making application to other areas more difficult.

Long-Run vs. Short-Run

Economic theory predicts that goods, such as water, which are complementary to capital investment and which involve use habits, show a response to price which varies according to how many of the complementary goods or habits can be adjusted. Since most such adjustments can occur only with the passage of time, the price response is expected to grow over time (as the full adjustment to price change is phased in). In the case of water, this may be complicated by uncertainty over behavior in the first few billing cycles after a price change ("announcement effect," etc.). Still, short-run (corresponding to short-term, with time scale on the order of months up to one year) response is expected to be more inelastic than long-run (long-term with time scale on the order of several years or more) reactions.

Only a few studies report comparable data for short-run and long-run elasticities. All of these find the short-run response more inelastic than long-run demand, as predicted. One study (Carver and Boland 1980) found short-run response to be nearly zero (elasticity = -0.05), while Agthe and Billings (1980) recorded a relatively small movement in the direction of inelasticity (a range of -0.18 to -0.36 for the short-run, compared to -0.27 to -0.50 for the long-run).

Few investigators have employed the time-series data and dynamic models necessary to develop short-run and long-run estimates from the same data set. No studies of short-run vs. long-run elasticities have been performed for the nonresidential sectors. While not critically important for long-range forecasting or demand modeling generally, short-run elasticity estimates are very useful in rate design and revenue forecasting activities. Short-run estimates may also be relevant to drought management planning, where the short-term response to emergency price changes is of interest.

Nonresidential Water Use

Very little effort has been devoted to estimating price elasticity for nonresidential user classes. In spite of the considerable importance of commercial and industrial water use in many systems, little is known of the response of these users to changes in price.

In the industrial area, attention has been given to a few specific categories by a few investigators. The results, which show great variability among categories, demonstrate that much more must be done before any real understanding of price response in this sector can be developed.

The commercial sector has been almost entirely ignored. A single study was found, which develops elasticity estimates for a few categories. Most commercial and institutional use does not fall into these categories, and its price response is still unknown.

REFERENCES

Agthe, Donald E., and R. Bruce Billings. 1980. Dynamic Models of Residential Water Demand. Water Resources Research 16(3):476-80.

Bain, J. S., R. E. Caves, and J. S. Margolis. 1966. Northern California's Water Industry. Johns Hopkins University Press: Baltimore, Maryland.

Baumann, D. D., J. J. Boland, J. H. Sims, B. Kranzer, and P. H. Carver. 1979. The Role of Water Conservation in Water Supply Planning. U.S. Army Engineer Institute for Water Resources. Fort Belvoir, Virginia.

Ben-zvi, Samuel. 1980. Estimates of Price and Income Elasticities of Demand for Water in Residential Use in the Red River Basin. U.S. Army Corps of Engineers. Tulsa, Oklahoma.

Ben-zvi, Samuel. 1980. Estimates of Price and Income Elasticities of Demand for Water in Industrial Use in the Red River. U.S. Army Corps of Engineers. Tulsa, Oklahoma.

Billings, R. B., and D. E. Agthe. 1980. Price Elasticities for Water: A Case of Increasing Block Rates. Land Economics 56(1):73-84.

Billings, R. Bruce. 1982. Specification of Block Rate Price Variables in Demand Models. Land Economics 58(3):386-94.

Boland, J. J., D. D. Baumann, and B. Dziegielewski. 1981. An Assessment of Municipal and Industrial Water Use Forecasting Approaches. U.S. Army Engineer Institute for Water Resources. Fort Belvoir, Virginia.

Boland, J. J., Jane L. Pacey, Way-See Moy, Roland C. Steiner. 1983. Forecasting Municipal and Industrial Water Use: A Handbook of Methods. U.S. Army Engineer Institute for Water Resources. Fort Belvoir, Virginia.

Camp, R. C. 1978. The Inelastic Demand for Residential Water: New Findings. Journal of the American Water Works Association 70(8):453-58.

Carver, P. H. 1978. Price as a Water Utility Management Tool under Stochastic Conditions. Ph.D. Diss. Department of Geography and Environmental Engineering, Johns Hopkins University. Baltimore, Maryland.

Carver, P. H., and J. J. Boland. 1980. Short Run and Long Run Effects of Price on Municipal Water Use. Water Resources Research 16(4):609-16.

Cassuto, A. E., and S. Ryan. 1979. Effect of Price on Residential Demand for Water Within an Agency. Water Resources Bulletin 15(2):345-53.

Clark, Robert M., and Haynes C. Goddard. 1977. Cost and Quality of Water Supply. Journal of the American Water Works Association 69(1):13-15.

Conley, B. C. 1967. Price Elasticity of Demand for Water in Southern California. Annals of Regional Science. 1(1):180-89.

Danielson, L. E. 1979. An Analysis of Residential Demand for Water Using Micro Time-Series Data. Water Resources Research 15(4):763-67.

DeRooy, J. 1974. Price Responsiveness of the Industrial Demand for Water. Water Resources Research 10(3):405-6.

Dziegielewski, B., J. J. Boland, and D. D. Baumann. 1981. An Annotated Bibliography on Techniques of Forecasting Demand for Water. U.S. Army Institute for Water Resources. Fort Belvoir, Virginia.

Elliott R. D., and J. A. Seagraves. 1972. The Effects of Sewer Surcharges on the Level of Industrial Water and The Use of Water by Industry. Water Resources Research Institute, Report no. 70. University of North Carolina. Raleigh.

Ethridge, D. E. 1970. An Economic Study of the Effect of Municipal Sewer Surcharges on Industrial Water. Ph.D. diss. North Carolina State University, Raleigh.

Flack, J. E. 1965. Water Rights Transfers--An Engineering Approach. Ph.D. diss. Stanford University. Palo Alto, California.

Foster, H. S., Jr., and B. R. Beattie. 1979. Urban Residential Demand for Water in the United States. Land Economics 55(1):43-58.

Fourt, L. 1958. "Forecasting the Urban Residential Demand for Water." Unpublished Paper, Department of Economics, University of Chicago.

Gallagher, D. R., and R. W. Robinson. 1977. Influence of Metering, Pricing Policy, and Incentives on Water Use Efficiency. Technical Paper no. 19. Australian Water Resources Council. Canberra, Australia.

Gardner, B. D., and S. H. Schick. 1964. Factors Affecting Consumption of Urban Household Water in Northern Utah. Agricultural Experiment Station Bulletin. no. 449. Utah State University. Logan.

Gardner, Richard L. 1977. An Analysis of Residential Water Demand and Water Rates in Minnesota. Water Resources Research Center. Bulletin 96. University of Minnesota. Minneapolis.

Gibbs, Kenneth C. 1978. Price Variable in Residential Water Demand Models. Water Resources Research 14(1):15-18.

Gottlieb, M. 1963. Urban Domestic Demand for Water: A Kansas Case Study. Land Economics 39(2):204-10.

Grebstein, C. R., and B. C. Field. 1979. Substituting for Water Inputs in U.S. Manufacturing. Water Resources Research 15(2):228-32.

Grima, A. P. 1972. Residential Water Demand: Alternative Choices for Management. University of Toronto Press.

Grunwald, Orlen C., C. T. Haan, David L. Debertin, and D. I. Carey. 1976. Rural Residential Water Demand in Kentucky: A Econometric and Simulation Analysis. Water Resources Bulletin 12(5):951-61.

Hanke, S. H. 1970. Demand for Water Under Dynamic Conditions. Water Resources Research 6(5):1253-61.

Hanke, S. H., and Lennart de Mare. 1982. Residential Water Demand: A Pooled, Time Series, Cross Section Study of Malmo, Sweden. Water Resources Bulletin 18(4):621-25.

Hansen R. D., and R. Narayanan. 1981. A Monthly Time Series Model of Municipal Water Demand. Water Resources Bulletin 17(4):578-85.

Hittman Associates, Inc. 1970. Price, Demand, Cost and Revenue in Urban Water Utilities. Columbia, Maryland. NTIS PB 195 929.

Hogarty, Thomas F., and Robert J. Mackay. 1975. The Impact of Large Temporary Rate Changes on Residential Water Use. Water Resources Research. 11(6):791-94.

Howe, Charles W., and F. P. Linaweaver. 1967. The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure. Water Resources Research 3(1):13-32.

Howe, Charles W. 1982. The Impact of Price on Residential Water Demand: Some New Insights. Water Resources Research 18(4):713-16.

Jones, C. Vaughan, and John R. Morris. 1984. Instrumental Price Estimates and Residential Water Demand. Water Resources Research 20(2):197-202.

Lynne, Gary D., William G. Luppold, and Clyde Kiker. 1978. Water Price Responsiveness of Commercial Establishments. Water Resources Bulletin 14(3):719-29.

Male, J. W., C. E. Willis, and P. J. Babin. Analysis of the Water Rate Structure as a Management Option for Water Conservation. Water Resources Research Center publication no. 112. University of Massachusetts at Amherst.

Metcalf, L. 1926. Effect of Water Rates and Growth in Population Upon per capita Consumption. Journal of the American Water Works Association. 15(1):1-20.

Morgan, W. D. 1974. A Time Series Demand for Water using Micro Data and Binary Variables. Water Resources Bulletin 10(4):697-702.

Morgan, W. D., and J. C. Smolen. 1976. Climatic Indicators in the Estimation of Municipal Water Demand. Water Resources Bulletin 12(3):511-18.

Morris, J. R., and C. V. Jones. 1980. Water for Denver: An Analysis of the Alternatives. Environmental Defense Fund, Inc. Denver, Colorado.

Nordin, John A. 1976. A Proposed Modification of Taylor's Demand Analysis: Comment. Bell Journal of Economics 7(2):719-21.

Pope, R. M., Jr., J. M. Stepp, and J. S. Lytle. 1975. Effects of Price Change upon the Domestic Use of Water over Time. Water Resources Research Institute. Clemson University, North Carolina.

Primeaux, Walter J., and Kenneth W. Hollman. 1973. Price and Other Selected Economic and Socio-Economic Factors as Determinants of Household Water Consumption. In Water for the Human Environment: Proceedings of the First World Congress on Water Resources. Vol. 3. International Water Resources Association. Champaign, Illinois.

Rees, J. A. 1969. Industrial Demand for Water: A Study of SouthEast England. London School of Economics Research Monograph No. 3. London.

Renshaw, E. F. 1958. The Demand for Municipal Water. Unpublished Paper, Department of Economics, University of Chicago.

Ridge, R. 1972. The Impact of Public Water Pricing Policy on Industrial Demand and Reuse. General Electric Technical Information Series. Prepared for the Office of Water Resources Research, Deptartment of Interior. Philadelphia, Pennsylvania.

Seidel, H. F., and E. R. Baumann. 1957. A Statistical Analysis of Water Works Data for 1955. Journal of the American Water Works Association 42(12):1531-66.

Sewell, W. R. Derrick, and Leonard Roueche. 1974. Peak Load Pricing and Urban Water Management: Victoria, B.C., A Case Study. Natural Resources Journal 14(3):383-400.

Turnovsky, Stephen J. 1969. The Demand for Water: Some Empirical Evidence of Consumers'Response to a Commodity Uncertain in Supply. Water Resources Research 5(2):350-61.

Ware, J. E., and R. M. North. 1967. The Price and Consumption of Water for Residential Use in Georgia. Bureau of Business and Economic Research. School of Business Administration, Georgia State University. Atlanta.

Wong, S. T. 1972. A Model on Municipal Water Demand: A Case Study of Northeastern Illinois. Land Economics 48(1):34-44.

Young, C. E., K. R. Kinsley, and W. E. Sharpe. 1983. Impact of Residential Water Consumption of an Increasing Rate Structure. Water Resources Bulletin 19(1):81-86.

Young, R. A. 1973. Price Elasticity of Demand for Municipal Water: A Case Study of Tuscon, Arizona. Water Resources Research 9(4):1063-72.

Ziegler, Joseph A., and Stephen E. Bell. 1984. Estimating Demand for Intake Water by Self-Supplied Firms. Water Resources Research 20(1):4-8.

APPENDIX

Annotated Bibliography
Description of Data Bases by Abstract Number
Author Index

1 Agthe, Donald E., and R. Bruce Billings. 1980. Dynamic Models of Residential Water Demand. Water Resources Research 16(3):476-80.

Abstract:

In this article static, Fisher-Kaysen, Koyck, flow adjustment, and stock adjustment econometric models of the demand for residential water are tested for their ability to explain the monthly residential demand for water in Tucson, Arizona. Monthly data for the period January 1974-September 1977 were used to test the models. The variables that are included are monthly water consumption of the average household in 100 cubic feet (Q); marginal price of the average household in cents per 1000 cubic feet (P_{ms}); a bill difference variable (D_{as}); income per household in dollars per month (I); and evapotranspiration for Bermuda grass minus rainfall in inches (X). The difference variable (D_{as}) is included in the models because the Tucson water rates include both increasing-block and flat rate charges. The D_{as} variable will measure the income effect of alterations in the flat rate or service charge. The price, difference, and income variables are adjusted by the consumer price index to establish real rather than nominal values.

The demand models are presented in both linear and logarithmic forms. The models that were found to be more highly significant and applicable are the static and dynamic Koyck models. The two models are presented as:

(1) Static

(a) Linear

$$Q = \underset{(-0.94)}{-15.2} - \underset{(-3.09)^*}{0.327 P_{ms}} - \underset{(-4.25)^*}{2.00\, D_{as}} + \underset{(2.41)^*}{0.0480\, I} + \underset{(10.22)^*}{0.0146\, X}$$

R^2 adj. = 0.801 F = 45.3 Df = N.R.

(b) Double-log

$$\text{Log } Q = \text{Log } \underset{(-1.36)^*}{-8.07} - \underset{(-1.56)^*}{0.264} \text{ Log } P_{ms} \underset{(-5.07)^*}{-0.124} \text{ Log } D_{as} + \underset{(1.89)^*}{1.70} \text{ Log } I + \underset{(9.33)^*}{0.0893} \text{ Log } X$$

R^2 adj. = 0.814 F = 48.0 Df = N.R.

(2) Koyck dynamic model

(a) Linear

$$Q = \underset{(-1.06)^*}{-16.1} - \underset{(-2.31)^*}{0.241\, P_{ms}} - \underset{(-3.37)^*}{1.58\, D_{as}} + \underset{(2.21)^*}{0.0415\, I} + \underset{(6.34)^*}{0.0114\, X} + \underset{(2.58)^*}{0.252\, Q_{t-1}}$$

R^2 = 0.830 F = 42.9 d.f. = N.R.

(b) Log

$$\text{LogQ} = \text{Log} \underset{(-1.33)^*}{-6.73} - \underset{(-1.22)}{0.179} \text{ Log } P_{ms} - \underset{(-3.78)^*}{0.0866} \text{ Log Das} + \underset{(1.73)^*}{1.33} \text{ Log I}$$

$$+ \underset{(6.66)^*}{0.066} \text{ Log X} + \underset{(3.94)^*}{0.326} \text{ Log } Q_{t-1}$$

R^2 adj. = 0.864 F = 55.8 Df = N.R.

The values in parentheses are t-statistics, and the * indicate significance at the 0.10 level or better. The variable Q_{t-1} is included to account for adjustments from the previous time period. None of the models demonstrated significant autocorrelation (Durbin-Watson test). The P_{ms} variable in the Koyck logarithmic model was significant at the 0.15 level.

In the Koyck model the short-run price elasticities are -0.358 and -0.179, linear and log forms, respectively. Elasticities of the linear models are calculated at the means. For both the Koyck and static models the long-run price elasticities range from -0.266 to -0.486. Again for both models, the long-run difference elasticities range from -0.124 to -0.149. The authors do not present a price elasticity result which accounts for the effect of price on the bill difference term.

Data Base Information:

Study Area Data

Location and water users: residential water users in Tucson, Arizona.
Mean summer temperature: 85 degrees F.
Mean summer precipitation: 5 inches.
Mean summer evapotranspiration: 21 inches.
Mean summer moisture deficit: 18 inches.
Water rates: increasing block rates and flat rates.
User sector: all residential (all single family apartments, condominiums, mobile homes, duplexes, and triplexes served with individual water connections).
Area character: urban.

Water Use Data

Maximum number of cases: not specified.
Type of measurement: secondary data from City of Tuscon, Arizona Department of Economic security, and U.S. Weather Bureau.
Measurement period: January 1974-September 1977.
Dependent variable: monthly water consumption per household.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: not specified.
Price variable specification: (1) marginal price of average user in sample, (2) Nordin's bill difference for average user.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: short run: -0.179 to -0.358, long run: -0.266 to -0.497.

Bill difference elasticities: long run: -0.124 to -0.144. No estimate is provided of total price elasticity, considering both price and effect of price on bill difference.

2 Bain, Joe S., Richard E. Caves, and Julius Margolis. 1966. Northern California's Water Industry. Johns Hopkins University Press. Baltimore, Maryland.

Abstract:

From a cross-section of 41 California cities in 1955, the authors analyzed the price elasticity of urban water, using aggregate municipal data. The sample was spatially biased in that Southern California was overrepresented and the Central Valley underrepresented. This was due to the Central Valley cities being served by private utilities or utilizing flat rates, both being excluded from the sample. Furthermore, there was high negative correlation between price and average temperature because of lower pricing policies in Southern California. Therefore, a multiple regression analysis would have overestimated price elasticity. A simple regression analysis was performed using logarithms of annual quantity per capita as the dependent variable and the logarithms of average price as the independent variable. The analysis estimated a statistically significant price elasticity of -1.099. The value is suspect because of the data problems noted. No coefficients or statistical tests were reported.

Data Base Information:

Study Area Data

Location and water users: sampled 41 waterworks systems in California.
Mean summer temperature: 65-75 degrees F.
Mean summer precipitation: 0-2 inches.
Mean summer evapotranspiration: 9-15 inches.
Mean summer moisture deficit: 7.8-15 inches.
Water rates: varied rates in multi-site data, however, no cities that used flat rates were included in the sample.
User sector: aggregate municipal.
Area character: urban.

Water Use Data

Maximum number of cases: not specified.
Type of measurement: secondary data from waterworks systems.
Measurement period: 1955-56 fiscal year.
Dependent variable: average annual water use per capita (gallons).
Estimating technique: regression analysis.
Price variable specification: average price for all customers of utility.

Minimum, maximum, and mean variable values:

P = \$1.30-\$3.60 per 1,000 cubic feet in 1955 (no mean value reported).
P = \$1.30-\$5.20 (1,000 cubic feet in 1960 (no mean value reported).
Q = 14,000-154,000 gallons in 1955-56 fiscal year (no mean).

Price elasticity: -1.099 (average price).

3

Ben-Zvi, Samuel. 1980. Estimates of Price and Income Elasticities of Demand for Water in Residential Use in the Red River Basin. U.S. Corps of Engineers. Tulsa, Oklahoma.

Abstract:

This report describes a cross-sectional comparison of nonindustrial (i.e., residential) water use in 20 communities located in the Red River Basin extending from northwest Louisiana to northwest Texas. In-house, sprinkling, and annual average water use models are estimated separately for three subregions of the area.

The estimated equations for the three types of water use in the eastern subregion are:

(1) In-house

$$\log Q_{ih} = \underset{(-1.26)}{-4.16} + \underset{(2.58)^*}{1.09} \ln I - \underset{(-3.32)^*}{0.794} \ln P_{ms} + \underset{(1.62)}{0.62} \ln H$$

$$R^2 = 0.81 \quad F = 22.4 \quad d.f. = 3,16 \quad N = 20$$

(2) Sprinkling

$$\ln Q_s = \underset{(-0.19)}{-13.1} + \underset{(0.98)}{1.80} \ln I \underset{(-2.13)^*}{-0.821} \ln P_{ms} + \underset{(0.25)}{0.44} \ln I_s \underset{(-0.13)}{-0.27} \ln F_s$$

$$R^2 = 0.38 \quad F = 3.69 \quad d.f. = 4,7 \quad N = 12$$

(3) Annual average

$$\ln Q_a = \underset{(-6.19)^*}{-1.07} + \underset{(1.25)}{0.64} \ln I - \underset{(-2.57)^*}{0.734} \ln P_{ms} + \underset{(1.68)}{0.78} \ln H + \underset{(1.65)}{0.07} \ln T$$

$$- \underset{(-0.23)}{0.11} \ln F_s$$

$$R^2 = 0.88 \quad F = 8.56 \quad d.f. = 5,6 \quad N = 12$$

Where: Q_{ih} = daily in-house water use per nonindustrial customer in each community in gallons calculated by dividing the lowest monthly total nonindustrial water sales by the number of residential units in the community; Q_s = sprinkling demand obtained by subtracting average daily winter use from average daily summer use in gallons per day per connection; Q_a = average annual water use in gallons per day per connection. The independent variables are: I = per capita income; P_{ms} = marginal price for each community; H = number of residents per dwelling unit; T_s = average summer temperature (June, July, August, September) in degrees F; and, F_s = total summer precipitation for the four-month period in inches. The numbers in parantheses show t-values, while asterisks indicate coefficients significant at the 0.05 probability level, or better.

Price elasticity coefficients for the above models are: -0.794, -0.821, and -0.734; all statistically significant at the 0.05 level. The regression coefficients and their significance are similar in the models estimated for samples from central and western regions of the study area, with price and income elasticities being consistently the lowest for each type of water use in the western subregion.

Data Base Information:

Study Area Data

Location and water users: 58 communities in Red River Basin (Northwest Louisiana to Northwest Texas).
Mean summer temperature: 76.5 degrees F.
Mean summer precipitation: 1-14 inches.
Mean summer evapotranspiration: 17-20 inches.
Mean summer moisture deficit: 11-17 inches.
Water rates: water rates vary among communities, but prevailing tariff is decreasing block with minimum service charge and minimum allowance.
User sector: residential (nonindustrial).
Area character: urban.

Water Use Data

Maximum number of cases: 20 observations in one equation.
Type of measurement: secondary; data provided by U.S. Army District.
Measurement period: 1978.
Dependent variable: daily in-house water use per nonindustrial customer (gallons); sprinkling demand in gallons per day per connection; average annual water use in gallons per day per connection.
Summer season definition: June, July, August, September.
Winter season definition: not specified.
Estimating technique: OLS regression.
Price variable specification: marginal price for each community.

Minimum, maximum, and mean variable values:

Q_{ih} = mean: 308 gallons/day/connection.
Q_s = mean: 141 gallons/day/connection.
Q_a = mean: 344 gallons/day/connection.
P_{ms} = mean: \$0.79/1000 gallons.
H = mean: 2.80 persons/household.
T_s = mean: 76.5 degrees F.
F_s = mean : 17.7 inches.

Price elasticities: -0.794, -0.821, -0.73 for in-house use, sprinkling demand, and average annual use, respectively.

4 Ben-Zvi, S. 1980. Estimates of Price and Income Elasticies of Demand for Water in Industrial Use in the Red River. Report prepared for the U.S. Army Corps of Engineers, Tulsa District. Tulsa, Oklahoma.

Abstract:

This report describes an analysis of the use of self-suppled water by 84 firms within six two-digit SIC categories. Food, lumber, paper, chemicals, petroleum, and clay industries were included. The estimated equations for these categories are:

(1) Food industry (SIC 20)

$$\ln Q = -5.4358 - 2.4186 \ln P_W + 0.6385 \ln X$$
$$(-13.79) \quad (-3.85) \quad (3.55)$$

$R^2 = 0.84$ F = 54.92 d.f. = 2,21

(2) Lumber industry (SIC 24)

$$\ln Q = 3.8097 - 0.5570 \ln P_W + 1.0183 \ln X$$
$$(-11.56) \quad (-0.92) \quad (5.63)$$

$R^2 = 0.98$ F = 72.86 d.f. = 2,3

(3) Paper industry (SIC 26)

$$\ln Q = -3.6829 - 0.5624 \ln P_W + 1.994 \ln X$$
$$(-2.61) \quad (-2.48) \quad (3.24)$$

$R^2 = 0.66$ F = 10.51 d.f. = 2,11

(4) Chemical industry (SIC 28)

$$\ln Q = -5.6649 - 1.4668 \ln P_W + 0.9930 \ln X$$
$$(-7.91) \quad (-4.05) \quad (3.71)$$

$R^2 = 0.69$ F = 17.18 d.f. = 2,15

(5) Petroleum industry (SIC 29)

$$\ln Q = -4.8470 - 0.1522 \ln P_W + 1.0610 \ln X$$
$$(-12.16) \quad (-2.60) \quad (11.79)$$

$R^2 = 0.95$ F = 82.41 d.f. = 2,9

(6) Stone and clay industry (SIC 32)

$$\ln Q = -3.2937 - 1.1271 \ln P_W + 0.6726 \ln X$$
$$(-8.72) \quad (-2.08) \quad (5.98)$$

$R^2 = 0.92$ F = 45.37 d.f. = 2,7