TR- 86
1978

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A Cross-Sectional Investigation of the Determinants of Urban Residential Water Demand in the United States, 1960-1970

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RESEARCH PROJECT COMPLETION REPORT

Project Number S-5201

(September 1, 1975 to August 31, 1978)

A CROSS-SECTIONAL INVESTIGATION OF THE DETERMINANTS OF URBAN RESIDENTIAL WATER DEMAND IN THE UNITED STATES, 1960 AND 1970

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A report contributing to

THE HOUSEHOLD DEMAND FOR URBAN WATER
SUPPLIES EMPHASIZING THE SOUTHWESTERN UNITED STATES

The work upon which this publication is based was supported in part by funds provided by the Office of Water Research and Technology, Department of Interior as authorized under the Water Resources Research Act of 1964, P.L. 88-379.

Technical Report No. 86
Texas Water Resources Institute
Texas A&M University

May 1978

ABSTRACT

This research was undertaken to specify and estimate a model relating household demand for urban water to its principal determinants. Four specific tasks were accomplished:

1. An appropriate economic demand model for urban-residential water supplies was postulated. An improved specification of the rainfall variable was developed to account for turf maintenance demand. The price of water was specified in exponential form making its elasticity price dependent.
2. Parameters of the model were estimated based on pooled data representing a cross-section of U.S. cities.
3. Parameters were estimated for a regionalized version of the model by incorporating sets of dummy variables. Tests for statistical differences among key economic coefficients were made to ascertain regional differences, if any.
4. Parameters were estimated for a model disaggregated by size-of-city categories again by incorporating dummy variable sets. Tests for statistical differences among key economic coefficients were made to ascertain differences among size-of-city categories, if any.

The demand models were fitted using 1960 and 1970 data and ordinary least squares regression techniques. Explanatory variables included price, income, precipitation (during the defined growing season) and number of residents per meter in addition to sets of dummy variables

on the constant factor and price and income coefficients. The results suggest that size of city is not statistically significant in determining the residential demand for urban water. However, regional differences are significant.

For the regional model, price, income, and residents per meter were significant at the 1 percent level for the 1960 data; price and precipitation were significant at the 1 percent level for the 1970 data. R^2-values were .74 and .71 for the 1960 and 1970 data, respectively.

Income and price elasticities are presented for all regions at the mean price level and for one standard deviation above and below this price level. Mean price level elasticities ranged between -.30 and -.82 and between -.33 and -.67 for the 1960 and 1970 data, respectively, suggesting an inelastic residential water demand at present price levels. The elasticity estimates derived from the regional coefficients of this study compare favorably with those of earlier more micro-level analyses.

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A CROSS-SECTIONAL INVESTIGATION OF THE DETERMINANTS OF URBAN RESIDENTIAL WATER DEMAND IN THE UNITED STATES, 1960 AND 1970

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INTRODUCTION

In the past half century the United States has been transformed from a rural to an urban society, and this process continues today. A necessary concomitant has been the development of an adequate water supply for residential, commercial, industrial and other urban uses.

Between 1960 and 1970 the United States experienced a 19.2 percent increase in urban population. Four states had an increase of 40 percent or more; an additional eighteen states experienced increases of 20 to 39 percent (U.S. Bureau of Census, 1970). If this urban growth continues, substantial expenditures will be required to provide needed water supplies. To assure adequate water-supply facilities, yet prevent overinvestment and wasteful expenditure of scarce resources, careful studies of effective economic demand are needed. Additional interest in economic demand has been brought about by recent severe drought in several regions and by the realization that water supplies are finite and that efficient allocation requires knowledge of economic demand. This study was undertaken to determine effective economic demand in the residential sector.

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Shortcomings of the Traditional Approach

In the past, the water supply industry has forecast water requirements generally under the assumption that urban water use will increase in some fixed relation to an increase in economic activity and population. If the existing system capacity did not meet the anticipated requirements, additional capacity was designed, an analysis of cost was conducted to determine the utility's new revenue requirements, and rates were set at a level which, at the new output level, would generate the needed revenue (Hanke 1975). While this procedure may have worked in the past, it is clear that in a time when additional supplies will be very costly, a more serious look at demand responsiveness to price is in order if major overinvestment in water supply capacity is to be avoided. Until the late 1960s relatively abundant natural endowments, technological change and improved operating efficiencies generated economies of scale and reduced the cost of urban water, resulting in very stable rate levels and an apparently fixed rate structure. Since that time, however, general price inflation has begun to exert a significant influence. For example, the Fairfax County Water Authority (Virginia) had wage increases of 58 percent and a chlorine price increase of 164 percent from 1968 to 1974. Additionally, environmental requirements increased the need for capital goods at a time when the prices of capital and capital goods were rising at a precipitous rate (Hanke 1975).

Clearly to expand supply capacity needlessly represents a significant waste of resources. In the past, a system which forecast demand without considering price effects had minimum faults. The rate of inflation was low, real per capita income was increasing slowly and predictably, and improvements in scale economies militated against increases in the price of water. Competition with other uses for scarce water supplies was not serious. In effect, the economically relevant variables, price and income, could safely be assumed constant for any given city over the planning horizon and were effectively treated as implicit parameters in the demand equation. This past stability does not seem as likely in the future. The effects of changes in real income and/or the real price of water must be considered if a spurious estimation of future urban water demand is to be avoided.

Limitations of Past Econometric Models

Past econometric studies of residential water demand have tended to have three major weaknesses limiting their usefulness. Broadly based studies using cross-sectional data have tended to be underspecified in terms of the explanatory variables included in the models. On the other hand, studies using cities from a restricted geographical area, in effect, minimized variation in some of the variables so that these factors, relevant in a general model, are eliminated from consideration in the specialized models. This allowed tests of specific hypotheses, but resulted in models underspecified in terms of the general determinants of residential water demand. Yet another specification problem is characteristic of many previous studies. Frequently water demand models have included redundant explanatory variables. In such cases the consequence is highly correlated independent variables, inflated standard errors and estimated coefficients which may deviate greatly from their true values.

Louis Fourt produced the most notable nationwide, aggregate demand models. Using multiplicative models and 1955 data, he regressed per capita water use on price (for the first 1,000 cubic feet of water used per month), number of days of rainfall in June, July and August, average number of persons per meter, and total population served. The results, based on a sample of 44 cities, indicated a price elasticity of -.39 with an R^2 of .68. Subsequently, per capita water use was regressed on price, per capita income, and percentage of dwellings with three or more units per dwelling. Price elasticity was -.39 but R^2 was only .30. The models were improperly specified in that the rainfall variable was crude in one model, and both rainfall and income were not included as variables in the other model.

Gottlieb selected small towns in Kansas to eliminate the effects of the size of city and rainfall, leaving price as the only variable having substantial variance. For 19 towns in 1952 a price elasticity of -1.74 and income elasticity of .45 with a R^2 of .83 was estimated. For 24 towns in 1957 the R^2 was .85 with a price and income elasticity of -.68 and .58, respectively.

Headley used the same analytical framework, selecting fourteen cities in the San Francisco-Oakland area. These cities had very similar rate schedules, and rainfall and temperature were assumed constant across observations, leaving variation in water demand as a function of median family income. Income elasticities were estimated to be 1.37 (1959) and 1.63 (1950) with R^2-values of .69 and .77, respectively. The technique used in these studies allowed very simple models and eliminated problems involved in multiple regression.

Howe and Linaweaver used 39 study areas covering the entire U.S. to establish five broad categories, each homogeneous in its physical, climatic and economic characteristics. Price and income elasticities for metered public sewer areas were estimated to be -.23 and .35, respectively. In flat-rate septic areas, population density was a dominant factor affecting demand. It was determined that sprinkling demand is significantly more price elastic than domestic demand. Property value, a proxy for income, was found to be the major factor affecting demand in flat-rate areas.

Hanke (1970) analyzed data before and after the conversion from flat-rate to water metering in the Boulder, Colorado utility. He found that use of water decreased after meter installation, both for sprinkling and use within the home. He believed this large decrease represented a once-and-for-all change in use brought about by introducing a positive marginal cost.

These regionalized studies tend to verify expected theoretical characteristics of residential water demand. Therefore, it was belived that a more general, Fourt-type model, properly specified, could be formulated which would account for all of the major determinants of residential water demand. This conjecture is implicit in the hypotheses of this study.

Hypotheses

Two general hypotheses provided motivation for this research:

1. Residential water demand is invariant among subregions of the U.S.
2. Residential water demand is invariant among city-size strata.

Failure to reject these hypotheses would suggest that a separate study may not be required for every city contemplating the impact of water pricing changes on its residential water demand. One overall analysis, performed periodically to update parameter estimates, might provide adequate assessment of the effects of economic factors on future water demand for any city. This could reduce the need for conducting individual studies for each city or at least provide general estimates so that micro-level studies could be limited in scope and focus on specific factors unique to the city in question, thereby saving a great amount of research time and expense.[1]

In a later section of this report, statistical data are reported which provide a basis for rejecting the hypothesis of no significant regional differences in the demand for urban residential water supplies. However, a similar test of no significant size-of-city effects resulted in a failure to reject. Given these results, a regionalized version of the general model is proffered. This single equation regression model provides estimates for individual city water-price elasticities that conform well to those of earlier regionalized (localized) studies.

Objectives

The purpose of this study was to formulate an improved model relating household demand for urban water to its principal determinants.

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[1]The model permits any city to estimate its quantity of water demanded given its relevant explanatory variable values. However, the confidence interval for a given city would be broader than the confidence interval for the mean of a group of observations at the specificed values of the independent variables (see Ostle and Mensing, p. 172).

The model was specified on a per household basis in order that the principal economic and climatological factors influencing demand at this level might be segregated from the effects of population growth. To wit, the study focused on the implications of economic factors as determinants of *household* water demand, and may thus be used with more conventional studies of projected growth to determine the overall level of demand for domestic supplies of water.

Five specific objectives were involved:

1. An appropriate economic demand model for households was postulated in multiplicative (log-linear) form.
2. Parameters of this aggregate model were estimated using pooled data for a broad cross-section of U.S. cities.
3. Parameters of a model disaggregated by region were estimated to statistically test for differences in the constant terms[2] and price and income coefficients among regions.
4. Parameters of a model disaggregated by size of city were estimated to statistically test for differences in the constant terms and price and income coefficients among size-of-city categories.
5. Price and income elasticity estimates were derived based on the "best" model.
6. These estimates were compared with those from earlier studies.

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[2]The expressions, constant term and constant factor, are used interchangeably throughout this report to refer to the parameter, β_o, of models like $Y=\beta_o X_1^{\beta_1} X_2^{\beta_2}$ whether in multiplicative form or its log-linear transformation.

The results of research to accomplish these objectives are presented in the following sections of this report. The report concludes with a summary of the important findings and their policy implications.

AN AGGREGATE U.S. DEMAND MODEL: THEORY AND METHODLOGY

Meaningful economic analysis requires knowledge of theory as well as statistical and mathematical considerations. This combined knowledge is needed to correctly specify the relationships of the system, perform the analysis and interpret the results.

The neoclassical theory of consumer behavior postulates four determinants of quantity demanded--the price of the good, prices of related commodities, income, and tastes. Consideration of these factors suggests the following single equation model as representing the demand function for urban residential water:

$$Q = f(P, Y, R, N)$$

where

Q = average quantity of water demanded per household, i.e., per meter (1000 cubic feet per year);

P = average water price (dollars per 1000 cubic feet);

Y = median family income (dollars per year);[3]

R = precipitation during the defined growing season;

N = average number of persons per meter.

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[3]Median rather than mean family income was chosen as an explanatory variable because the *1960 Census of Population* reports median rather than mean data, and average values are unduly influenced by extreme values in the data set.

The variables Y, R, and N act as shifters of demand in the price-quantity plane. Justification for inclusion of this set of independent variables in the demand model is discussed in the following section.

Choice of Independent Variables

Water is used to meet physiological and psychological needs. However, studies attempting to delineate these factors have been disappointing. Linaweaver, Geyer, and Wolff found that many variables influence water use, and identification of the most important factors is largely dependent on the design of the data collection program.

Residential water use may be broadly categorized as necessities of life, concommitants of modern living, and horticultural activities.[4] As a necessity of life, water is used for cooking, drinking, bathing, and waste disposal. Bathing and waste disposal consume large quantities of water and are amenable to conservation given economic incentives. Washing machines, dishwashers, garbage disposals, swimming pools, and some types of air conditioning are uses of water considered essential for modern living. Each of these activities requires a capital expenditure, and thus use is no doubt highly correlated with income. Proper management of many of these items can save substantial amounts of water. Horticulture and turf maintenance comprise a substantial seasonal demand for water. The size of lawn or garden is a major factor in the quantity demanded. Other factors include plant species and weather conditions.

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[4]For an extensive summary of factors that may affect the level of residential water consumed per dwelling unit, see Grima, pp. 34-36.

Price

It is sometimes suggested that price has very little, if any effect on water consumption. However, this suggestion seems unlikely as the price of a consumer good is normally the most important single factor affecting quantity demanded. A consumer responds to price because of limited income (and savings). To buy more of any commodity requires that something of utility be given up. The trade-off will be greater the higher the price of the commodity and the lower the income of the consumer. Howe and Linaweaver empirically tested the hypothesis that quantity demanded does not respond to price. They were able to reject the hypothesis at the one percent significance level. Both economic theory and past empirical evidence suggest that the price of water is an important variable in explaining differences in quantities of water demanded.

Generally, demand models include as variables the prices of closely related goods (substitutes and complements) as well as the price of the commodity itself. Water, however, has no close substitutes. It is complementary to other goods only in the sense that it is used with appliances such as washing machines. These "complementary goods" are in fact, durable items which depreciate over a long period. Once the household has its supply of these durable items, their price will not affect the use of water. This is in contrast with nondurable complementary goods such as foods which must be purchased at frequent intervals. Thus, all cross-price effects in the water demand model were assumed negligible, and only the price of water was included.

Income

The size of the yard as well as the number and efficiency of water using appliances are highly correlated with income. Many past studies (Gardner and Schick; Primeaux and Hollman; Ware and North) have included numerous variables such as per capita value of homes, per capita lot area, number of bathrooms per household, and use of a washing machine as explanatory variables in addition to income. However, all of these variables are interrelated. An adequate income is required to purchase these items, and because of the household's budget constraint, the amount of each item purchased will affect the availability of funds to purchase other items. A high correlation between these variables will cause a near singular matrix and highly inflated variance estimates, effectively destroying the usefulness of the model for hypothesis testing. In contrast, only median household income was used in this study to account for all effects highly correlated with income. By so doing, important multicollinearity problems were avoided.

Climate and Weather

In addition to price and income which are commonly included variables in the demand functions for virtually all goods, climatic and weather conditions have considerable influence on residential demand for water. The effects of extremes of temperatures and precipitation especially influence residential water demand for horticultural purposes. Mean annual precipitation in the U.S. varies from less than eight inches in the Southwest to more than 128 inches in some coastal areas of Washington. Mean monthly average temperatures during January range from 0^{o} F. in North Dakota to greater than 60^{o} F. in south Texas and Florida. During July and August, average temperatures range from less than 60^{o} F. in some mountainous areas of the West to greater than 90^{o} F. in parts of California and Arizona (United States Department of the Interior, Geological Survey). A general, multivariate model must account for this wide variation in weather and climate if their influence on demand at any given location is to be determined.

Fourt used the number of days of rainfall in June, July and August as an independent variable to account for the effects of weather in his cross-sectional analysis of 44 cities. However, Bain, Caves, and Margolis noted that coastal areas of California have a twelve-month growing season, and interior valleys have only a slightly shorter growing season, suggesting that rainfall during the summer months alone may not be the appropriate specification of this variable. Other studies have considered annual rainfall and average number of rainy days from May through September (Lauria and Chiang) and evaporation from June through September (Grunerwald, Haan, Debertin, and Carey). It is evident that this important component of urban water demand deserves additional attention.

The moisture available for use in turf maintenance (in the absence of irrigation) is equal to rainfall less runoff, percolation, and evapo-transpiration. Unfortunately, comprehensive methods for estimating the moisture available for any particular area require data and resources that are not available for a cross-sectional analysis of more than 200 cities as in this study. Consequently, a surrogate variable involving precipitation and average temperature (available on a monthly basis) was used in this study to account for the effects of weather.[5] Specifically, R was defined as the sum of the rainfall for all months in which the average temperature is equal or above a threshold level. Rainfall and temperature determine the suitability of various grasses for any climatic region. Temperature is the limiting factor because irrigation may be used to supplement insufficient rainfall. Generally, turf grasses are classified into cool-season grasses and warm-season grasses. Basically, cool-season-grass roots start to grow when soil temperatures reach 40-45^{o} F., but their roots become quiescent at a soil temperature of approximately 80^{o} F. In contrast, a warm-season grass such as Bermuda is dormant until soil temperature approaches 60^{o} F., and growth is not limited by hot weather if nutrients and water are available (Vengris).

The U.S. may be divided into regions according to the grass species used for turf (see Figure 1). Warm-season species predominate in the southern region, and cool-season species predominate in the northern region. Therefore, inches of rainfall was included during those months in which the average monthly temperature was a minimum of 45^{o} and 60^{o} F. in the northern and the southern regions, respectively.

Number of Residents Per Meter

The analysis was conducted on a "per household" (average household per city) basis, the standard consuming unit. However, essential uses

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[5]Wisler presents a complete list of factors which affect infiltration capacity. Chow presents a method for estimating the runoff from precipitation. Moe presents a simple method for estimating evapo-transpiration. Ideally, each of these techniques would be incorporated into a model for estimating the household demand for water in horticultural use.

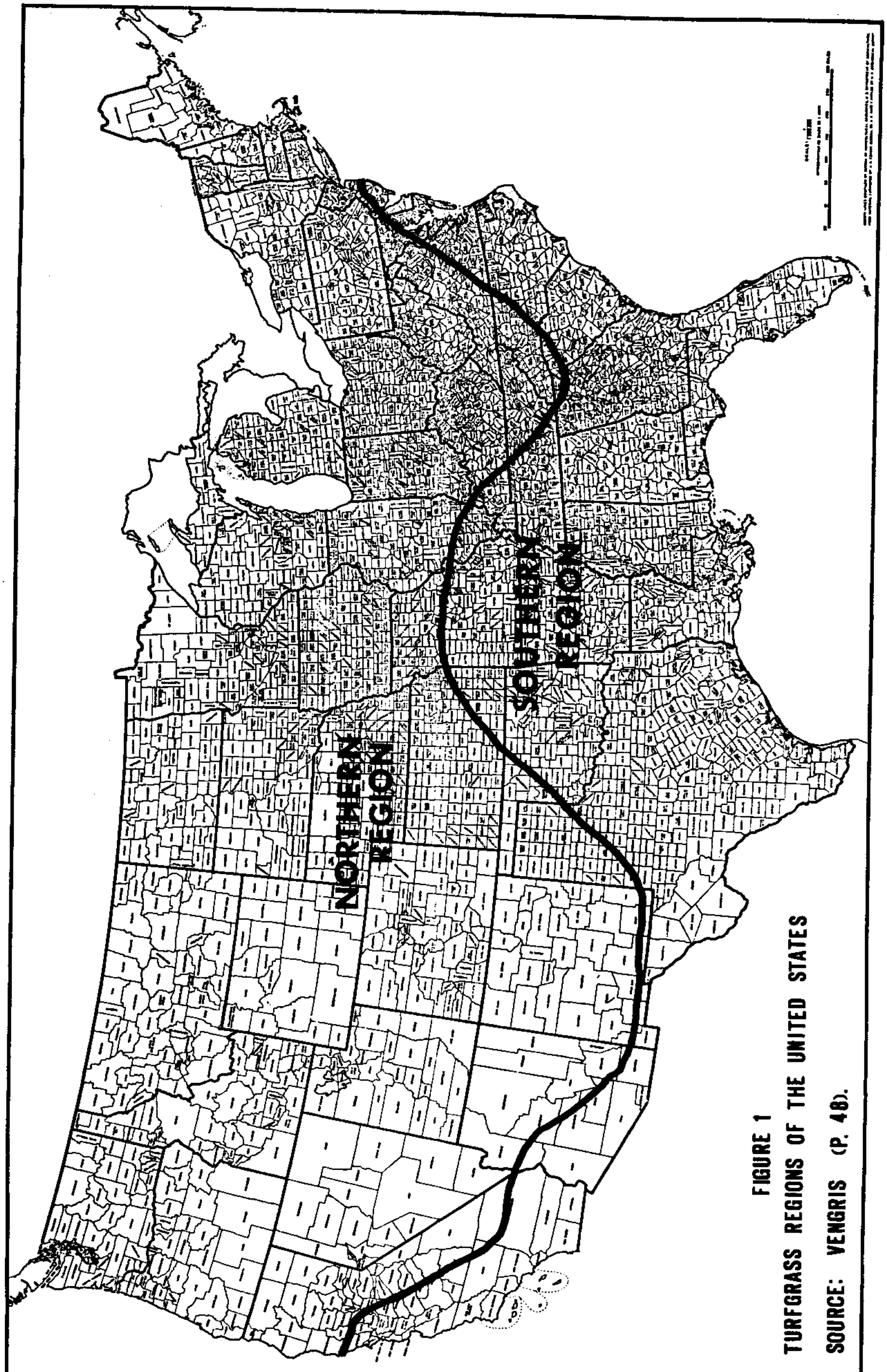

FIGURE 1
TURFGRASS REGIONS OF THE UNITED STATES
SOURCE: VENGRIS (P. 48).

such as bathing, waste disposal, and laundry may vary with the size of the household as limited economies of scale are possible. Howe and Linaweaver found, "Population density in terms of the number of persons per dwelling unit strongly affects domestic demands in flat-rate and septic tank areas" (p. 37).

Apartments and multi-family dwellings which have a single meter for multiple units would, in effect, greatly inflate the number of persons per meter. In addition, these consumers are effectively on a flat-rate basis as water is provided by the owner as part of his contractual obligation. Therefore, the average number of persons per service meter was included in the model to account for this variation.

Choice of Functional Form

In addition to determination of variables to be included in a model, the other important consideration in model specification is choice of functional form. This choice is probably not particularly critical if one is interested only in small variations from the mean. However, if a purpose of the model is to consider the impact of possible changes in the independent variables at some distance from mean values, the reliability of the model will very likely be sensitive to the functional form chosen. Prior knowledge and theory are essential in this aspect of model formulation.

Because water is a necessity of life, tremendously high rates would be paid for water, if necessary, suggesting that the price-quantity curve would approach the price axis asymptotically. Also, there is probably a limit to the use of water, even at a zero marginal price, implying an intercept of the quantity axis. A price-exponential demand curve has these properties.[6]

Consider the single independent variable function,

$$Q = \beta_o e^{\beta_p P}$$

This function takes on a value of β_o when P equals zero, which represents the quantity of water consumed when the marginal price of water is zero. In addition, assuming a negative value of β_p (consistent with a downward sloping demand curve), quantity approaches zero as price increases without limit.

This functional form has another desirable feature from a theoretical and policy viewpoint when contrasted with a power model. The price elasticity of demand is given by $\beta_p P$ and thus varies directly with P. It seems unlikely that the price elasticity of a good would remain constant over wide price ranges. It has been verified that the residential demand for water is generally inelastic at existing price levels. If the price elasticity of water is inelastic and constant, then rising price levels will result in an ever increasing proportion of the consumer's income being required for the purchase of water. As the relative proportion of the budget required to purchase any good increases, the constrained utility maximization process of the consumer implicitly results in changes in price elasticities. If this were not true, an ever increasing proportion of the budget would be devoted to the purchase of the good at the expense of other want-satisfying

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[6] Another popular functional form, the power form of the demand model, is discussed, and parameter estimates related thereto are presented in Foster.

goods. First order conditions for maximizing consumer's utility would be violated because the same level of utility could be secured at less cost by substituting other goods for the one whose price has risen. This result is due to the convexity of the indifference curves.

Prais and Houthakker's seminal work on consumer budget studies provides insight on the issue of choice of functional form for demand function estimation. Although their study was undertaken for the purpose of estimating income elasticities rather than price elasticities, their logic is applicable for the latter as well. They concluded that exponential functions were preferable to power functions. They believed that the income elasticity of most goods is a declining rather than constant function of the level of income. They also found that when both functional forms were evaluated at mean values of the variables, the power function elasticity tended to be higher. However, there is no *a priori* reason for assuming that the income elasticity of water is a decreasing function of income. On the contrary, while this seems logical in the extreme, it seems likely that the income elasticity of water increases for the range of incomes in this and most studies because more affluent consumers generally purchase larger homes with more spacious yards and more water using appliances.

With no specific evidence that income elasticity is an increasing or decreasing function, income was postulated, as were the remaining explanatory variables, in double-logarithmic (power) form. The price-exponential model hypothesized was as follows:

$$(1) \qquad Q = \beta_k \, e^{\beta_p P} \, Y^{\beta_y} \, R^{\beta_r} \, N^{\beta_n} \, \varepsilon$$

where

Q = average quantity of water demanded per household in 1000 cubic feet per year per meter;

P = average water price in dollars per 1000 cubic feet;

Y = median family income in dollars per year;

R = precipitation during the defined growing season (see previous section);

N = average number of persons per meter;

β_k, β_p, β_r, β_n = parameters;

ε = error term.

This aggregate U.S. demand model is modified in the following section to reflect possible categorical effects owing to regional and size-of-city differences.

THE DISAGGREGATED DEMAND MODELS: THEORY AND METHODOLOGY

As noted earlier, two hypotheses provided motivation for this research. It was believed that the household residential demand for water is invariant to city size and invariant among regions of the U.S. If these hypotheses are not rejected, a single demand model with one set of parameter estimates would adequately explain the role of economic factors in determining residential water demand. From this single demand model, estimates of quantity demanded and price and income elasticities could be deduced. On the other hand, if the hypotheses are rejected, it should be possible to specify a single equation demand model with appropriate dummy variables to account for regional and/or city size differences, thereby reducing somewhat the need for individualized studies of the effects of economic factors influencing water demand.

The Respecified Models

Several models of increasing complexity were formulated to test the null hypotheses that household water demand is invariant among regions and size-of-city categories. In the first respecification dummy variables were added for β_k, allowing it to vary among categories. In the second respecification dummy variables were incorporated for β_k and β_p. In the final respecification dummy variables were included for β_k, β_p, and β_y, allowing all relevant economic factors to vary among cateogries. The respecified price-exponential models, listed in order of increasing complexity, are

$$\text{(1a)} \quad Q = e^{\beta_o} e^{(\sum_i \beta_{oi} V_i)} e^{\beta_p P} Y^{\beta_y} R^{\beta_r} N^{\beta_n} \varepsilon$$

$$\text{(1b)} \quad Q = e^{\beta_o} e^{(\sum_i \beta_{oi} V_i)} e^{\beta_{po} P} e^{(\Sigma \beta_{pi} V_i P)} Y^{\beta_y} R^{\beta_r} N^{\beta_n} \varepsilon$$

$$\text{(1c)} \quad Q = e^{\beta_o} e^{(\sum_i \beta_{oi} V_i)} e^{\beta_{po} P} e^{(\Sigma \beta_{pi} V_i P)} Y^{\beta_{yo}} \prod_i Y^{(\beta_{yi} V_i)} R^{\beta_r} N^{\beta_n} \varepsilon$$

where

V_i = 1 if the observation is from the i^{th} category (region or city)

= 0 otherwise

i = 1, 2, ... , 6 for regional models and i = 1, 2, 3, 4 for size-of-city models.

The final result is six additional models, three used with the basic model (equation 1) to test for regional differences and three used with the basic model to test for size-of-city differences. The V_i's represent regions in testing for regional differences and city size categories in testing for differences in size of city.

An F-statistic was used to test for significance of the dummy coefficients using a stepdown procedure. The F-test indicates whether using a less complex model (with fewer parameters) significantly increases the residual mean square above that of the more complex model. The basic model and the three regional models were presented in increasing order of complexity. Then the most complex model (model c) was compared to the second most complex model (model b). If the F-test was non-significant, no advantage was gained by using the more complex model, and it was eliminated. Model b was then compared to model a, and the stepdown approach was continued until further simplifications became statistically significant. The process was repeated using the basic model and the three size-of-city versions of the demand model.

Selection of Regions

Criteria

Ideally, a delineation of U.S. subregions to test for regional variation in residential water demand should consider climatic, economic, social, cultural, and topographical factors. Each region should be as homogeneous as possible; however, the wide variation in these factors would require numerous small regions and result in very small sample sizes. Thus, a compromise must be made between homogeneity of subregions and sufficient data points for statistical analysis.

Schroepfer and co-authors (p. 1075), in the first analysis of water works data, used seven geographical regions following state boundaries; the principal criterion being geographic proximity and historical precedent. This delineation has been followed by subsequent authors in analyses of water works data (Seidel and co-authors, 1953, 1957, 1966). A study of peak demands by the American Water Works Association used the Koepper classification to establish regions for analysis (Task Group Report). This classification, commonly used by geographers, is based solely on climatic considerations.

In these previous studies, economic, topographic, and cultural factors were not considered although each may have a role in influencing residential water demand. For purposes of this study, maps outlining physical divisions, drought potential, agricultural production patterns (a proxy for residential horticultural characteristics), manufacturing, and monthly precipitation were analyzed, albiet subjectively, as a basis for developing the regional delineation (U.S. Department of the Interior, Geological Survey). These regions are shown in Figure 2.

The Regions

Region one includes New England and the Appalachian Highlands. Precipitation is moderate, and droughts are of short duration. Poultry and dairy products are the most important agricultural industries. Manufacturing is very important in this region.

In region two, the Central Lowlands, precipitation is moderate, and the region is vulnerable only to droughts of short duration. It is an extremely important agricultural region with sorghum, corn, livestock, soybeans, wheat, and dairy products being the major agricultural products. Manufacturing is also very important in this region.

The Coastal Plain and the Appalachian Highlands form region three. Precipitation is moderate to heavy, and drought potential is of short

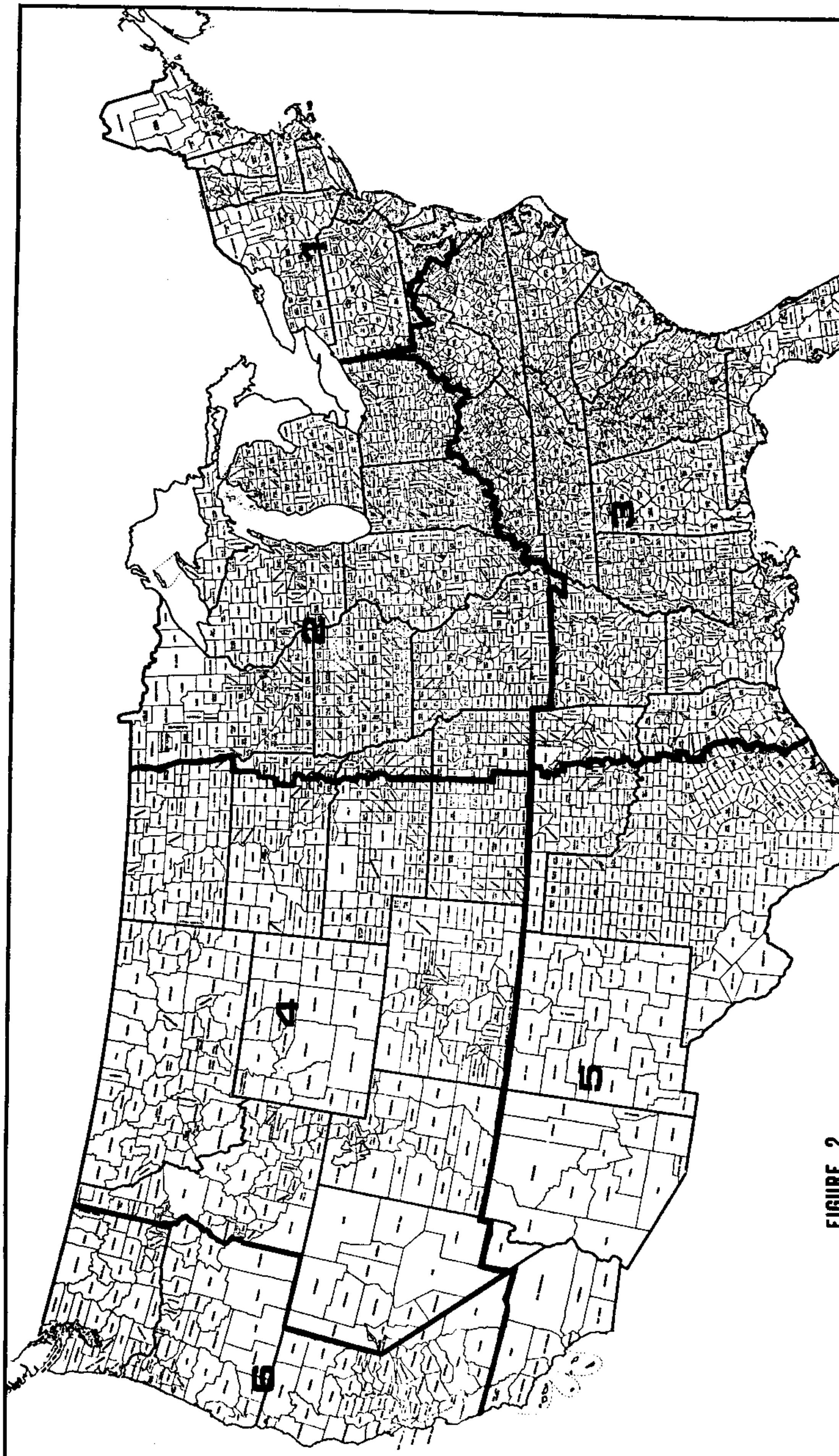

FIGURE 2
REGIONAL CLASSIFICATIONS USED FOR
HYPOTHESIS TESTS

duration. Cotton, poultry, and tobacco are important agricultural products. There is a moderate amount of manufacturing in the region.

Region four consists principally of the Great Plains and Rocky Mountain area. The region is arid, and droughts can be either of short or long duration. Important agricultural products include sorghum and wheat. The region has limited manufacturing.

Region five is principally composed of the Great Plains and the Intermountain Plateaus. The region is arid, and droughts may be of long or short duration. Wheat (in the eastern portion of the region), sorghum, livestock, and cotton are important agricultural products. Manufacturing is limited except for California and the Phoenix and Dallas areas.

Region six, including the Cascade-Sierra Mountains and the Columbia Plateaus, is arid except for bands of very heavy precipitation along the Pacific coast. Drought potential is of long duration (except for the coastal areas), and manufacturing is important in the western portion of this region.

Selection of Size-of-City Categories

Analyses of data by Schroepfer and Seidel and co-workers (1953, 1957, 1966) gave little indication of any effect of size of city on demand (on a per capita basis). For all the surveys, cities with a population of 10,000 or more were broken down into six groups modified from United States Census Bureau groupings existing at the time of the first analysis. Per capita water production by population groups had little effect except for the largest group of cities with a population over 500,000. For this category production was 16 percent above the

U.S. average in 1945, 25 percent above in 1950, but only approximately 5 percent above the average in 1955 and 1960. (These figures are for total water produced, and not residential production alone.) There was a consistent tendency for the number of consumers per residential service connection to increase with the size of city, and per capita expense and revenue dropped as the size of city increased.

Since no theoretical or institutional reasons for establishing specific population limits for each group were found, data for this study were divided into four groups, each containing sufficient observations to constitute adequate statistical samples. The groups are cities in which:

(1) Population $\leq$ 20,000

(2) 20,000 < Population $\leq$ 50,000

(3) 50,000 < Population $\leq$ 150,000

(4) 150,000 < Population

In the following section estimates are presented of the demand functions for the price-exponential models. This is followed by the results of the hypothesis tests and the selection of the "best" model from which price and income elasticity estimates are derived. Results for a power specification of the models are presented in Foster.

EMPIRICAL RESULTS

To test the hypotheses that urban residential water demand is invariant among subregions of the U.S. and among city size strata, equations 1, 1a, 1b and 1c were fit using ordinary least squares. In all, parameters were estimated for seven equations for each of the years, 1960 and 1970. That is, the aggregate U.S. model (equation 1) and two sets of the disaggregate models (one set for regional and one for size-of-city effects) were fitted for 1960 and 1970. Statistics from these regressions were used for the hypothesis tests.

Sources of Data

Data for the analysis were obtained from secondary sources. These include data published by the American Water Works Association and the U.S. Departments of Commerce and Interior. *A Summary of Operating Data for Water Works in 1960* and *Operating Data for Water Utilities, 1970 and 1965* were the data sources for water utility information. These sources provided information on revenue produced from residential services, total number of residential meters, number of gallons consumed in revenue-producing residential service and population served. This information was used to construct a cross-sectional data series for quantity of water consumed per residential meter (household), price paid for water, and number of residents per meter.

Data on median family income for all cities in the analysis were obtained from *The 1960 Census of Population* and *The 1970 Census of Population*. Average monthly temperature and monthly precipitation were taken from *Climatological Data for the United States*. If a city did not have an official reporting point, information was substituted from the closest reporting city. Study data are summarized in the Appendix.

The Aggregate U.S. Model -- 1960 Data

The resulting estimated equation for the price-exponential form of the aggregate U.S. model was

$$(2) \quad Q = .2492\, e^{\underset{(10.71)}{-.1278P}}\; Y^{\underset{(4.69)}{.4619}}\; R^{\underset{(6.79)}{-.1679}}\; N^{\underset{(3.69)}{.4345}} \qquad R^2 = .544$$

T-statistics are listed in parentheses below parameter estimates. The aggregate U.S. model was tested for the hypothesis:

$$H_o: \beta_p = \beta_y = \beta_r = \beta_n = 0$$

$$H_a: \text{not } H_o$$

with an F-test. The F-statistic of 63.69 with four and 213 degrees of freedom was significant at the .01 level. Each individual coefficient was then tested for statistical significance given the hypothesis:

$$H_{oi}: \beta_i = 0$$

$$H_{ai}: \beta_i \neq 0$$

Each hypothesis was tested using the student's t-statistic, and all regression coefficients were significant at the .01 level.[6]

Each coefficient had the expected sign. The negative beta coefficient for price indicates a downward sloping price-quantity relationship. A positive beta coefficient for income indicates increased usage of water as income increases. This is reasonable because generally consumers with larger incomes purchase larger homes with more lawn area and more water using appliances. The negative beta coefficient for rainfall indicates a decrease in residential water use as rainfall increases. A positive beta coefficient for residents per

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[6]T-statistics for the individual coefficients are not independent because the explanatory variables are correlated (see Appendix Tables 3 and 4). This dependence will affect the actual level of significance of the t-tests because the "Student's" t-distribution is based on the assumption of statistical independence.

meter indicates that a larger family uses more water, a reasonable supposition.

The Disaggregated Models--1960 Data

The aggregate U.S. model was modified to allow for differences among regions and size of city categories by incorporating dummy (binary) variables. Three specific forms were hypothesized for both regional and size of city variations of the models (see equations 1a, 1b and 1c).

Hypothesis Tests

It was hypothesized that residential water demand is invariant among subregions of the U.S. and invariant among city size strata. If true, the inclusion of dummy variables should not increase the explanatory power of the model. Accordingly, the following hypothesis was tested, first for regional and then for city size differences, using an F-test:

$$H_{io}: \ \beta_{di1} = \beta_{di2} = \cdots = \beta_{din} = 0$$

$$H_{ia}: \ H_{io} \ \text{not true}$$

The estimated aggregate U.S. model, the three disaggregated by region models, and the three disaggregated by size of city models provided the required statistics.

The testing was performed using a stepdown analysis. In this procedure, the models were presented in increasing order of complexity as indicated by the number of parameters estimated (see Table 1). The most complex model was tested against the second most complex model

TABLE 1

SUMMARY OF HYPOTHESIS TEST STATISTICS FOR REGIONAL AND SIZE-OF-CITY EFFECTS, 1960

Source of Variation	Regional Effects				Size-of-City Effects			
	df	Sum of Squares	Mean Square	F	df	Sum of Squares	Mean Square	F
Total	217	43.092						
Basic Equation	4	SSR: 23.470						
Residual	213	SSE: 19.622						
Additional Dummy Variables for Constant Term	6	Reduced SSE: 7.492	1.498	25.70*	4	Reduced SSE: .014	.005	.05
Residual	207	SSE: 12.130	.058		209	SSE: 19.608	.014	
Additional Dummy Variables for Price Slope	6	Reduced SSE: .974	.195	3.54*	4	Reduced SSE: .143	.048	.51
Residual	201	SSE: 11.156	.055		205	SSE: 19.465	.094	
Additional Dummy Variables for Income Slope	6	Reduced SSE: .296	.059	1.08	4	Reduced SSE: .101	.034	.35
Residual	195	SSE: 10.860	.055		201	SSE: 19.365	.095	

*Indicates statistical significance at the one percent level.

to determine whether the last set of additional explanatory variables was statistically significant in explaining variation in quantity of water demanded. If this last set of variables was not statistically significant, the most complex model was discarded, and the second most complex model was tested against the third most complex model. The stepdown process continued until a statistically significant F-value was found.

The most complex model (1c), which includes dummy variables for the income coefficient, as well as the constant and price coefficients, was tested against model 1b which includes dummy variables only for the constant factor and price coefficient. An F-statistic of 1.08 was not significant, even at the .10 level, indicating that the addition of binary variables for the income factor was not significant in explaining the variation in quantity of residential water demanded. A comparison of model 1b with model 1a, which included dummy variables only for the constant factor, resulted in an F-value of 3.54, significant at the .05 level. Thus, the hypothesis that demand is invariant among subregions was rejected.

The stepdown procedure applied to size-of-city statistics, gave F-values of .51, .35 and .05, respectively, at the three stepdown stages. The hypothesis that demand is invariant to city size cannot be rejected.

<u>The Selected Model</u>

Based on results of the hypothesis tests reported in the preceding section, the regionalized version of model 1b was selected as the model which best relates demand for urban residential water to its principal determinants. This model with dummy variables for the constant and price coefficients allowing variation in these coefficients among regions is

$$(3)\quad Q = e^{(-2.8207-.3243V_1-.5152V_2-.3251V_3+.3968V_4+.3100V_5+.4579V_6)}$$
$$\qquad\qquad (3.34)\quad (7.54)\quad (3.20)\quad (2.75)\quad (2.24)\quad (3.45)$$

$$e^{(-.1514+.0334V_1+.0710V_2+.0586V_3-.0747V_4+.0291V_5-.1172V_6)P}$$
$$(9.07)\ (1.42)\quad (3.58)\quad (2.29)\quad (1.47)\quad (.66)\quad (2.48)$$

$$Y^{.6274}\ R^{-.0403}\ N^{.3026} \qquad\qquad R^2 = .741$$
$$(7.27)\quad (1.67)\quad (3.21)$$

T-values are in parentheses beneath estimated coefficients.

The overall model was significant at the .01 level with an F-statistic of 41.51 with 14 and 203 degrees of freedom. Income, price and residents per meter were significant at the .01 level. In all regions, β_{oi} was significantly different from zero resulting in all β_{ki}'s being significantly different from the mean value--regions 1-4 and 6 at the .01 level and region 5 at the .05 level. Regions 2, 3, and 6 had a price coefficient significantly different from the average price coefficient--region 2 at the .01 level and regions 3 and 6 at the .05 level. All coefficients have expected signs.

The Aggregate U.S. Model--1970 Data

The estimated equation for the 1970 aggregate U.S. model, using price, median family income, growing-season precipitation[7], and average

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[7]A caveat must be noted here in that the 1970 data may be less reliable than the 1960 data with respect to the precipitation variable. In the 1960 AWWA survey, the fiscal year used by each participating utility was asked for and published. This was not done in the 1970 survey. This becomes important because data used for the precipitation variable were obtained from a separate source. Clearly the rainfall data need to be for the same time frame as the price-quantity and other data. To overcome this shortcoming in the 1970 data two assumptions were made. First, if a utility included in the 1970 data set also participated in the 1960 survey, then the fiscal year reported for that utility in 1960 was assumed for 1970. For those utilities included in 1970 that did not

number of persons per meter as explanatory variables, was

$$(4) \qquad Q = 5.2371\, e^{\underset{(11.26)}{-.1308P}}\; Y^{\underset{(1.91)}{.1768}}\; R^{\underset{(10.37)}{-.1408}}\; N^{\underset{(1.59)}{.1572}} \qquad R^2 = .577$$

with t-statistics listed in parentheses below parameter estimates. The model was significant at the .01 level; the F-statistic was 94.68 with 4 and 248 degrees of freedom. Each individual regression coefficient had its expected sign--price and income were significant at the .01 level; rainfall was significant at the .05 level; number of residents per meter was not significant.

The Disaggregated Models--1970 Data

A stepdown procedure was used to test for significance of the sets of dummy variables (constant term, price, and income) as for the 1960 model. However, in the 1970 data the correlations between the income dummy variables and constant term dummy variables was nearly one for all regions, indicating extreme multicollinearity. Therefore, equation 1c was not considered in the 1970 model stepdown analysis.

Equation 1b with dummy variables for regional categorical effects on the constant term and price was again selected, based on the F-tests, as the equation best relating demand to its principal determinants.

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participate in the 1960 survey, a calendar fiscal year was assumed. This assumption seems defensible because 62 percent of the water utilities included in the useable 1960 data were on a calendar fiscal year.

The estimated equation was

$$(5)\quad Q = e^{\underset{}{(-.1824} - \underset{(.58)}{.0598V_1} - \underset{(6.61)}{.5346V_2} - \underset{(1.23)}{.1364V_3} + \underset{(.14)}{.0240V_4} + \underset{(2.40)}{.3096V_5} + \underset{(2.88)}{.3973V_6})}$$

$$e^{(\underset{(10.31)}{-.1412} - \underset{(.44)}{.0100V_1} + \underset{(3.62)}{.0654V_2} - \underset{(.14)}{.0034V_3} - \underset{(.05)}{.0020V_4} - \underset{(.05)}{.0018V_5} - \underset{(1.33)}{.0482V_6})P}$$

$$\underset{(4.05)}{Y^{.3673}}\ \underset{(2.22)}{R^{-.0360}}\ \underset{(1.09)}{N^{.0940}} \qquad\qquad R^2 = .709$$

with t-statistics in parentheses.

The overall model was significant at the .01 level with an F-statistic of 41.43 with 14 and 238 degrees of freedom. Price and income were significant at the .01 level; rainfall was significant at the .05 level. For regions 2, 5, and 6, the constant term dummy coefficients were significantly different from zero (β_{02} and β_{06} at the .01 level; β_{05} at the .05 level). Region 2 had a dummy price coefficient significant at the .01 level. Dummy price coefficients for other regions were not significant. All coefficients have expected signs.

Economic Interpretation of the Statistical Results

Reliable estimates of price and income elasticities are essential for good planning in all resource development projects including water. The effect of a price change on demand and revenue should be considered before expensive construction takes place.

The rejection of the hypothesis that per household water demand is invariant among subreions of the U.S. is significant in the planning of water resource development. A uniform policy change will have different effects in different regions. Inferences applicable to one region of the country cannot be made indiscriminately throughout all regions.

Failure to reject the hypothesis that per capita (household) water demand is invariant to size-of-city criteria simplifies economic interpretation. In interpreting data and drawing policy implications city size need not be considered a relevant factor.

Demand Curves

A demand curve is a two-dimensional representation showing the quantity of a good demanded at different price levels. Implicit in any demand curve are other factors which influence demand. For any given demand curve these other factors are held constant at some fixed value. These other factors serve as "demand shifters" in the price-quantity plane. In this study, income, rainfall and number of residents per meter are demand shifters. Furthermore, the regional dummy variables also act as demand shifters reflecting differences among regions. The regionalized versions of the demand equations for 1960 and 1970 are presented in Table 2. Corresponding demand curves are displayed in Figures 3 and 4. It should be noted that these curves assume mean values of income, precipiation, and number of residents per meter for each respective region.

Price and Income Elasticity Estimates

Price elasticity of demand is defined as

$$\varepsilon_p = \frac{\partial Q}{\partial P} \frac{P}{Q}$$

and gives the percentage change in quantity demanded attributable to an infinitesimally small percentage change in price, *ceteris paribus*.

TABLE 2

ESTIMATED PARAMETERS FOR THE REGIONAL FORMS OF THE SELECTED MODEL (1b)*, 1960 AND 1970

Region	β_k	β_p	β_y	β_r	β_n
1960 Data					
1. New England and North Atlantic	.04307	-.1180	.6274	-.0403	.3026
2. Midwest	.03558	-.0804	.6274	-.0403	.3026
3. South	.04303	-.0928	.6274	-.0403	.3026
4. Plains and Rocky Mountains	.08858	-.2261	.6274	-.0403	.3026
5. Southwest	.08121	-.1223	.6274	-.0403	.3026
6. Northern Calif. and Pacific Northwest	.09416	-.2686	.6274	-.0403	.3026
1970 Data					
1. New England and North Atlantic	.7848	-.1511	.3673	-.0360	.0940
2. Midwest	.4882	-.0758	.3673	-.0360	.0940
3. South	.7270	-.1446	.3673	-.0360	.0940
4. Plains and Rocky Mountains	.8534	-.1432	.3673	-.0360	.0940
5. Southwest	1.1355	-.1429	.3673	-.0360	.0940
6. Northern Calif. and Pacific Northwest	1.2397	-.1893	.3673	-.0360	.0940

*Model: $Q = \beta_k e^{\beta_p P} Y^{\beta_y} R^{\beta_r} N^{\beta_n}$ where $\beta_k = e^{\beta_o + \beta_{oi}}$ and $\beta_p = \beta_{po} + \beta_{pi}$ from equations 3 and 5 (pp. 30 and 32) where the subscript i denotes the region.

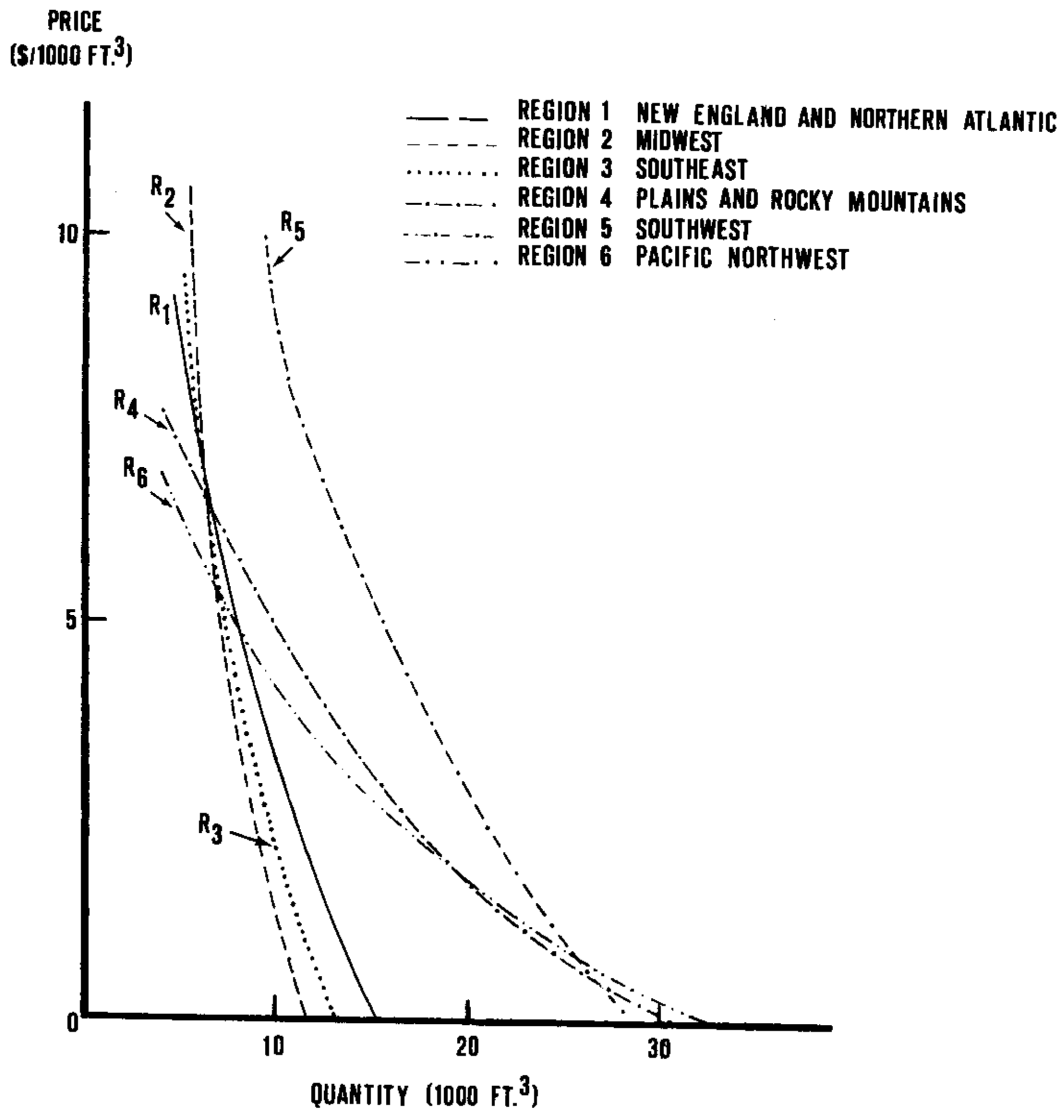

FIGURE 3

ESTIMATED DEMAND CURVES FOR THE PRICE-EXPONENTIAL MODEL BY REGION, 1960 (INCOME, PRECIPITATION AND NUMBER OF RESIDENTS PER METER HELD CONSTANT AT THEIR RESPECTIVE MEAN VALUES FOR EACH REGION)

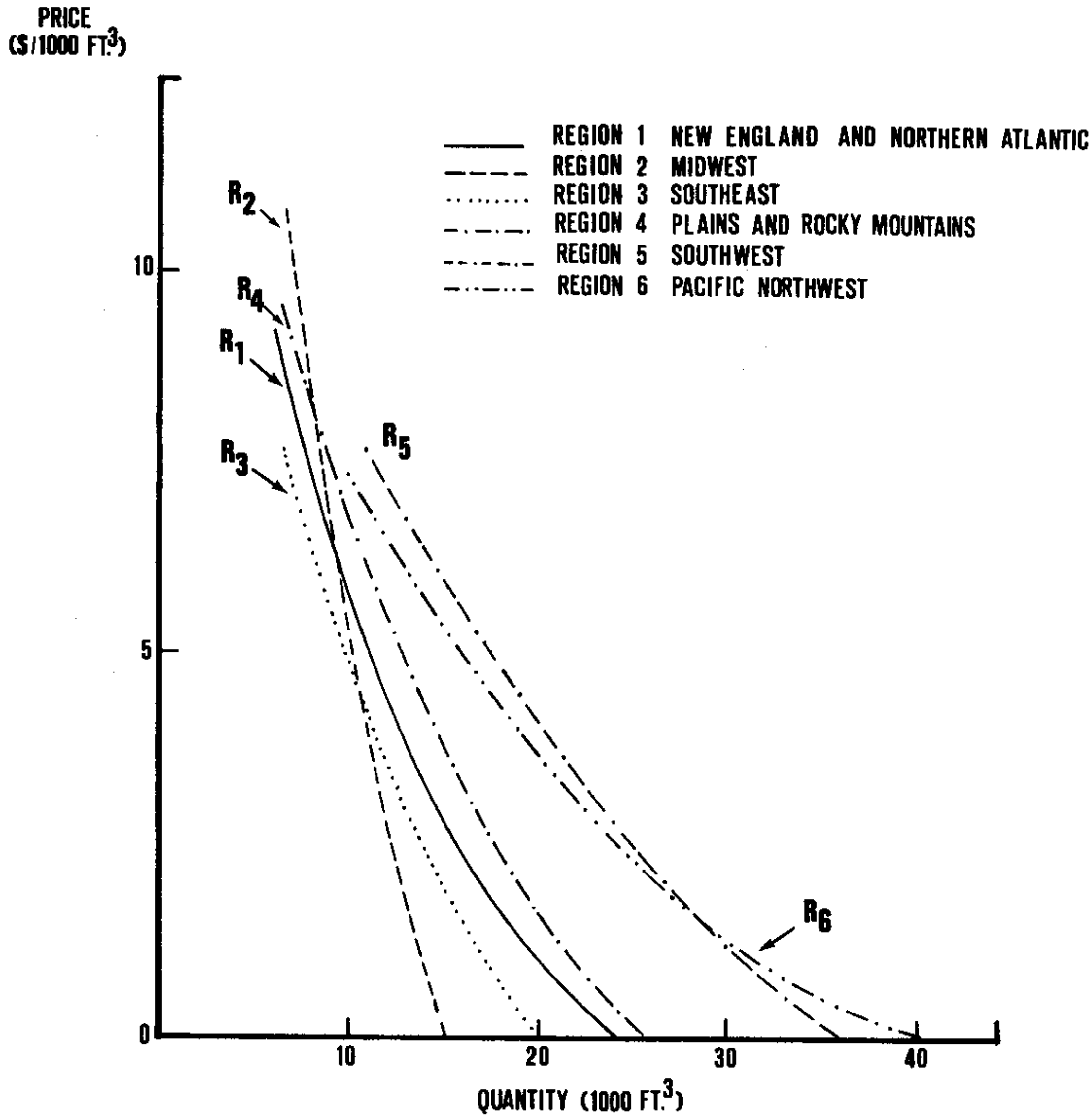

FIGURE 4

ESTIMATED DEMAND CURVES FOR THE PRICE-EXPONENTIAL MODEL BY REGION, 1970 (INCOME, PRECIPITATION AND NUMBER OF RESIDENTS PER METER HELD CONSTANT AT THEIR RESPECTIVE MEAN VALUES FOR EACH REGION)

Similarly, income elasticity is defined as

$$\varepsilon_y = \frac{\partial Q}{\partial Y} \frac{Y}{Q}$$

For the price-exponential model the price elasticity, $\varepsilon_p = \beta_p P$, varies directly with the price of water. No other variables have any effect on its value. Income elasticity is constant for all income levels as well as other variable levels, i.e., $\varepsilon_y = \beta_y$.

Price and income elasticities for the price-exponential model are presented in Table 3. These values are derived from the parameters estimated for regionalized versions of equations 1b as given in Table 2.

Differences Among Regions

For purposes of this discussion a region is said to be unique with regard to per household urban-residential water demand if the dummy coefficient on the constant factor (β_k) or price coefficient (β_p) is statistically different from zero. In 1960, all regions were unique assuming a .05 significance level. The constant factor for each region differed significantly from its average value while the price coefficients for regions 2, 3 and 6 were significantly different from the average value of the price coefficient in the selected equation.

In 1970, only regions 2, 5 and 6 were unique. Region 2 had both a constant factor and a price coefficient different from the average values of the equation, while regions 5 and 6 were significantly different only in the constant factor.

A Comparison of Price Elasticity Estimates With Those of Previous Studies

A thesis of this research is that a general urban residential water demand model could be formulated that would be applicable for

TABLE 3

PRICE AND INCOME ELASTICITY ESTIMATES BY REGION, 1960 AND 1970

Region	Relative Price Level	1960 Data Price	1960 Data ε_p	1960 Data ε_y	1970 Data Price	1970 Data ε_p	1970 Data ε_y
1. New England and North Atlantic	Mean + one std. dev.	6.37	-.75	.63	6.15	-.93	.37
	Mean	4.37	-.52	.63	4.29	-.65	.37
	Mean - one std. dev.	2.37	-.28	.63	2.42	-.37	.37
2. Midwest	Mean + one std. dev.	5.48	-.44	.63	6.22	-.47	.37
	Mean	3.68	-.30	.63	4.30	-.33	.37
	Mean - one std. dev.	1.88	-.15	.63	2.39	-.18	.37
3. South	Mean + one std. dev.	5.61	-.52	.63	5.94	-.86	.37
	Mean	4.06	-.38	.63	4.28	-.62	.37
	Mean - one std. dev.	2.51	-.23	.63	2.61	-.38	.37
4. Plains and Rocky Mountains	Mean + one std. dev.	3.77	-.85	.63	5.67	-.81	.37
	Mean	2.55	-.58	.63	4.18	-.60	.37
	Mean - one std. dev.	1.33	-.30	.63	2.69	-.39	.37
5. Southwest	Mean + one std. dev.	4.05	-.50	.63	4.06	-.58	.37
	Mean	2.91	-.36	.63	3.07	-.44	.37
	Mean - one std. dev.	1.77	-.22	.63	2.09	-.30	.37
6. Northern Calif. and Pacific Northwest	Mean + one std. dev.	3.81	-1.02	.63	4.80	-.91	.37
	Mean	2.57	-.69	.63	3.57	-.68	.37
	Mean - one std. dev.	1.33	-.36	.63	2.33	-.44	.37

the entire U.S. If this contention is correct, the elasticity estimates from this study should compare favorably with those of previous "regional" studies.

Most previous studies have specified price in log-linear form implying a constant price elasticity. In contrast, the price elasticity for the price-exponential model varies directly with price, i.e., $\varepsilon_p = \beta_p P$. Thus, the comparisons presented in Table 4 are the constant elasticity estimates from earlier studies versus elasticity estimates from the appropriate regional models of this study. Our elasticity estimates were obtained by substituting into the elasticity formula each city's water price from the 1960 AWWA data.

Price elasticity estimates by Gottlieb (1957 data), Wong (1961 data), Gardner and Schick (1964 data), and Ware and North (1965 data) were compared with the results of our regionalized models based on 1960 data. Great Bend is the only small city in Kansas in the 1960 AWWA data meeting the criteria used by Gottlieb. Our price elasticity estimate of -.67 for Great Bend is extremely close to Gottlieb's estimate of -.69. Only one city from the Chicago metropolitan area (Calumet City) was represented in the 1960 data. .Kankakee, the only other city relatively nearby for which data were available, is included in the comparison. The estimates of -.27 and -.60 for these cities are within the range of values estimated by Wong (-.26 to -.82).

There were no Utah cities in our data, so Colorado Springs -- the nearest city -- was used for comparison since Utah and Colorado are both in region 4. Again, our estimate of -.76 is extremely close to the -.77 estimate reported by Gardner and Schick. No Georgia cities were included in our data, but Anniston and Huntsville, Alabama are

TABLE 4

A COMPARISON OF ELASTICITY ESTIMATES OF THIS STUDY WITH SEVERAL PREVIOUS STUDIES

Author	Year	ε_p	Cities Available for Comparison	Calculated Average Price ($/1000 ft^3)	β_p	ε_p
Literature			This Study--1960 Data			
Gottlieb	1957 (Kansas)	-.69	Great Bend	2.97	-.2261	-.67
Wong	1961 (Chicago Suburbs)	-.26 to -.82	Calumet City	3.45	-.0804	-.28
			Kankakee	7.52	-.0804	-.60
Gardner-Shick	1964 (Utah)	-.77	Colorado Springs	3.37	-.2261	-.76
Ware-North	1965* (Georgia)	-.61	Anniston	3.76	-.0928	-.35
			Huntsville	4.76	-.0928	-.44

*The 1965 data used in the Ware-North study is midway between the 1960 and 1970 data available for this study. While the estimates for Anniston and Huntsville (using the 1960 data) do not compare favorably with the Ware-North estimate, the estimates using the 1970 data are -.65 and -.55, respectively, very close to the Ware-North estimate.

relatively nearby and included for comparison. The estimates of -.35 and -.44 compare less favorably with the Ware-North estimate of -.61. However, the 1965 data used in the Ware-North study is midway between the 1960 and 1970 AWWA data. It could be that underlying factors have changed the price elasticity between 1960 and 1965. Therefore, additional estimates of price elasticity were made based on the 1970 results. These data yielded price elasticity estimates of -.65 and -.55, which are very close to the Ware-North estimate.

The price elasticity estimates of this study are surprisingly consistent with those of earlier regionalized studies. This consistency tends to support the idea that the results of this study have wide applicability for individual water works. Utility managers should find these estimates useful in predicting the impact of price changes on per capita consumption rates.

SUMMARY AND CONCLUSIONS

The purpose of this study was to develop a model relating residential demand for urban water to its principal determinants and test the hypotheses that per capita (household) residential water demand is invariant to city size and invariant among subregions of the U.S. To accomplish these objectives, theoretical and statistical properties of alternative models were weighed in choosing the variables and specifying the functional form of the demand model. Explanatory variables included were water price, household income, effective rainfall and residents per meter; the functional form adopted was log-linear with price appearing exponentially. Model parameters were estimated using ordinary-least-squares regression analysis.

Dummy variables were introduced to test for regional and size-of-city effects. The hypothesis that demand is invariant among regions was rejected. The hypothesis that demand is invariant among size-of-city categories could not be rejected (even at the .10 level).

The "best" model (based on a stepdown F-test criterion) with regional dummy coefficients on the "constant term" and the price coefficient accounted for 74 and 71 percent of the variation in the dependent variable (quantity of water demanded per household) in 1960 and 1970, respectively. All estimated coefficients had expected signs--negative on price and rainfall and positive on income and residents per meter. The coefficients on price and income were significant in both 1960 and 1970. Additionally, residents per meter was significant in the 1960 model, and rainfall was significant in the 1970 model. Dummy variable coefficients were significantly different from the base (national average) coefficient for all regions in 1960. In 1970, regions having "constant term" and/or price coefficients significantly different from the national average were the Midwest, Southwest, and Northern California and Pacific Northwest regions. The reasons for this different finding in 1960 and 1970 are not apparent. However, it may be that the 1960 results are more reliable than the 1970 results due to shortcomings in the 1970 data (see footnote 7, p. 30).

The overall performance of the model in terms of R^2 and significance of individual coefficients suggests some confidence in the quality of estimation. This confidence is further bolstered by the model's ability to yield price elasticity estimates for specific cities that are consistent with those of previous, more micro-level studies (see Table 4, p. 40). Accordingly, we believe the model and the individual parameter estimates to be useful in a policy context.

In 1970, price elasticity estimates implied by the model range from -.68 for the Northern California and Pacific Northwest region to -.33 for the Midwest region when evaluated at respective regional mean prices. Not surprisingly, the demand responsiveness to price changes is inelastic for all regions at or about the mean water price. Since the vast majority of utilities sell water at a price lower than that corresponding to the point of unitary elasticity (i.e., in the inelastic region of their demand curve), these utilities could increase total revenues from residential user by increasing price.

Perhaps of greater interest, as costs of developing potable water supplies continue to rise, is the question: what would be the expected reduction in per household residential water demand (i.e., the conservation effect) of an increased real water price *ceteris paribus?* Despite the fact that the demand for residential water is inelastic at present prices, water savings in response to increased water prices are not inconsequential. Our results suggest that a doubling of the present price of residential water would reduce per household demand by 49 percent in the Northern California and Pacific Northwest region and 28 percent in the Midwest region (the highest and lowest for the 1970 data). Further, a doubling of the real price of residential water would move us from an inelastic region of the water demand curve to an elastic region for most of the subregions of the United States. Increasing the real price of water could be used as a mechanism to curb projected increases in per capita residential water consumption and militate against the need for costly expansion of water supply facilities.

Perhaps it is appropriate to conclude by noting a limitation of this research, thereby identifying an opportunity for further research. While the AWWA data were available by residential, commercial, industrial and public categories, only annual data were reported. Monthly data would allow a more detailed investigation of inside the home versus sprinkling demand. (Climatological data were available on a daily basis.) There is considerable variation in demand seasonally, and water companies must plan to meet peak demands. This is particularly important in residential water demand because sprinkling demand is an important component of overall residential demand during summer months. Estimation of seasonal demands would show to what extent interseasonal price differentials could be used by management as a tool to regulate demand. Higher prices in summer would discourage sprinkling and certain other uses and reduce peak requirements. A comprehensive research effort in this area will be contingent on the availability of monthly and/or seasonal cross-sectional data.

Hopefully the estimates reported herein will be useful to policy makers and water utility managers in assessing the likely impacts and prospects for residential water demand management through the pricing mechanism. A greater emphasis on price to serve as an incentive for conservation in all areas of water use, including residential, would be consistent with policies suggested by the National Water Commission.

REFERENCES

American Water Works Association. Staff Report. *A Survery of Operating Data for Water Works in 1960.* New York: Amer. Water Works Assoc., 1964.

American Water Works Association. Staff Report. *Operating Data for Water Utilities 1970 and 1965.* New York: Amer. Water Works Assoc., 1973.

American Water Works Association. Task Group Report. "Study of Domestic Water Use." *J. Amer. Water Works Assoc.* 50(1958): 1408-18.

Bain, Joe S., Richard E. Caves, and Julius Margolis. *Northern California's Water Industry.* Baltimore: The John Hopkins Press, 1966.

Chow, Ven Te, Editor-in-Chief. *Handbook of Applied Hydrology.* New York: McGraw-Hill Book Co., 1964.

Foster, Henry S., Jr. "Estimation of the Urban Household Demand for Water in the United States." M.S. Thesis, Texas A&M University, 1977.

Fourt, Louis, "Forecasting the Urban Residential Demand for Water." Paper presented at the University of Chicago Agr. Econ. Sem., Chicago, Feb. 1958.

Gardner, B. Delworth, and Seth H. Schick. "Factors Affecting Consumption of Urban Household Water in Northern Utah." Bulletin 449, Agr. Experiment Station, Utah State University, Logan, Utah, Nov. 1964.

Gottlieb, Manuel. "Urban Domestic Demand for Water: A Kansas Case Study." *Land Econ.* 39(1963): 204-10.

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

Gruenwald, Orlen C., C. T. Haan, David L. Debertin, and D. I. Carey. *Rural Residential Water Demand in Kentucky: An Econometric and Simulation Analysis.* Res. Report No. 88, Water Resources Research Institute, University of Kentucky, Lexington, December 1975.

Hanke, Steve H. "Demand for Water Under Dynamic Conditions," *Water Resour. Res.* 6(1970): 1253-61.

________________. "Water Rates: An Assessment of Current Issues." *J. Amer. Water Works Assoc.* 67(1975): 215-19.

Headley, Charles. "The Relation of Family Income and Use of Water for Residential and Commercial Purposes in the San Francisco-Oakland Metropolitan Area." *Land Econ.* 39(1963): 441-49.

Howe, Charles W., and F.P. Linaweaver, Jr. "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure." *Water Resour. Res.* 3(1967): 13-32.

Lauria, Donald T., and Cheng H. Chiang. *Models for Municipal and Industrial Water Demand Forecasting in North Carolina.* Report No. 110, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, November 1975.

Linaweaver, F. P., Jr., J.C. Geyer and J. B. Wolff. *A Study of Residential Water Use.* Washington: Department of Housing and Urban Development, F.H.A., February 1967.

Moe, Roderick D. "The Development of a New Evaporation Formula for Texas." M.S. Thesis, Texas A&M University, 1965.

National Water Commission. *Water Policies for the Future.* Port Washington: Water Information Center, 1973.

Ostle, Bernard, and Richard W. Mensing. *Statistics in Research.* 3rd ed. Ames: The Iowa State University Press, 1975.

Prais, S.J., and H.S. Houthakker. *The Analysis of Family Budgets.* Cambridge: Cambridge University Press, 1955.

Primeaux, Walter J., and Kenneth W. Hollman. "The Effects of Price and Other Selected Variables on Water Consumption." *Proceedings of the First World Congress on Water Resources,* pp. 189-198. Vol. III, Chicago: September 24-28, 1973.

Schroepfer, G. J., A. S. Johnson, H. F. Seidel and M. B. Al-Hakim. "A Statistical Analysis of Water Works Data for 1945." *J. Amer. Water Works Assoc.* 40(1948): 1067-98.

Seidel, Harris F., and E. Robert Baumann. "A Statistical Analysis of Water Works Data for 1955." *J. Amer. Water Works Assoc.* 49(1957): 1531-66.

Seidel, Harris F., and John L. Cleasby. "A Statistical Analysis of Water Works Data for 1960." *J. Amer. Water Works Assoc.* 58(1966): 1507-27.

Seidel, Harris F., A. Stanford Johnson and Donald O. Dencker. "A Statistical Analysis of Water Works Data for 1945." *J. Amer. Water Works Assoc.* 45(1953): 1309-33.

U.S. Department of Commerce, Bureau of the Census. *1960 Census of Population,* vol. 1, *Characteristics of the Population, Parts 1-52.* Washington, 1963.

U.S. Department of Commerce, Bureau of the Census. *1970 Census of Population*, vol. 1, *Characteristics of the Population, Parts 1-52.* Washington, 1973.

U.S. Department of Commerce, U.S. Weather Bureau. *Climatological Data for the United States.* Asheville, 1960-61, 1970-71.

U.S. Department of the Interior, Geological Survey. *The National Atlas of the United States of America*, ed. Arch C. Gerlach. Washington D.C., 1970.

Vengris, Jonas. *Lawns: Basic Factors, Construction and Maintenance of Fine Turf Areas.* Indianapolis: Thomson Publications, 1969.

Ware, James E., and Ronald M. North. *The Price and Consumption of Water for Residential Use in Georgia.* Res. Paper No. 40, Bur. of Bus. and Econ. Res., School of Bus. Admin., Georgia State College, Atlanta, October 1967.

Wisler, C. O., and E. F. Brater. *Hydrology.* New York: John Wiley and Sons, Inc., 1959.

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

APPENDIX

SUMMARY OF DATA AND CORRELATION MATRICES

APPENDIX TABLE 1

SUMMARY OF DATA BY CATEGORIES, 1960

Region/City Size Number of Cities	Quantity per Meter (Q)		Price (P)		Median Income (Y)		Effective Rainfall (R)		Density (N)	
	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low
Region:*										
U.S. 218	10.89 (6.57)	49.80 4.76	3.67 (1.76)	10.24 .69	5936 (1588)	22177 2436	23.13 (9.26)	64.0 0.1	4.29 (.76)	7.33 1.84
Region 1 35	9.54 (6.42)	39.13 4.76	4.37 (2.00)	9.21 .69	6514 (2919)	22177 4406	26.39 (4.46)	35.9 16.0	4.40 (.82)	6.10 2.60
Region 2 97	8.76 (2.53)	20.03 5.33	3.68 (1.81)	8.83 1.29	6116 (894)	11957 3795	23.83 (5.69)	36.0 11.4	4.16 (.65)	6.31 1.84
Region 3 42	8.57 (2.99)	19.17 5.21	4.06 (1.55)	10.24 1.56	4896 (999)	7566 2835	28.80 (9.95)	64.0 16.0	4.36 (.75)	6.39 2.84
Region 4 12	17.93 (8.39)	39.88 8.43	2.55 (1.22)	4.75 .96	6016 (718)	7662 4970	13.82 (8.64)	31.9 3.6	4.35 (.61)	5.33 3.46
Region 5 18	20.38 (9.00)	49.80 11.79	2.91 (1.14)	5.54 1.30	5929 (1958)	11977 2436	12.25 (10.49)	29.9 0.1	4.78 (1.09)	7.33 3.19
Region 6 14	17.77 (9.75)	46.95 8.43	2.57 (1.24)	4.78 .76	6298 (733)	8368 5292	15.01 (13.01)	44.0 0.2	4.03 (.69)	5.83 3.21

(continued)

Appendix Table 1. (Continued).

Region/City Size Number of Cities	Quantity per Meter (Q)		Price (P)		Median Income (Y)		Effective Rainfall (R)		Density (N)	
	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low
<u>Size of City:</u>[†]										
Category 1	10.04	39.13	3.70	7.95	5735	11957	24.02	45.3	4.08	6.20
53	(5.72)	4.87	(1.53)	.69	(1427)	2436	(7.26)	3.5	(.76)	2.60
Category 2	11.41	49.80	3.57	10.24	6096	22177	23.23	48.1	4.24	7.33
80	(8.09)	5.19	(1.88)	.76	(2166)	3635	(9.36)	0.1	(.69)	2.84
Category 3	10.87	39.88	3.98	9.21	5910	8161	22.66	64.0	4.33	6.10
50	(6.25)	4.76	(2.02)	(1.56)	(987)	3755	(10.89)	0.2	(.64)	3.22
Category 4	11.03	23.36	3.39	6.69	5908	7527	22.20	45.0	4.67	6.39
35	(3.93)	5.21	(1.35)	1.32	(743)	3816	(9.46)	0.4	(.93)	1.84

[*] See Figures 2 and 3, pp. 22 and 35, for regional delineations and names.

[†] See p. 24 for size-of-city categories.

Source: Data relating to quantity per meter, price and density are from *A Survey of Operating Data for Water Works in 1960* (American Water Works Association). Median income data are from *1960 Census of Population* (U.S. Dept. of Commerce). Effective rainfall data are from *Climatological Data for the United States* (U.S. Dept. of Commerce, U.S. Weather Bureau).

APPENDIX TABLE 2

SUMMARY OF DATA BY CATEGORIES, 1970

Region/City Size Number of Cities	Quantity per Meter (Q)		Price (P)		Median Income (Y)		Effective Rainfall (R)		Density (N)	
	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low
Region:*										
U.S.	15.28	49.94	4.02	8.91	10155	28782	21.77	59.7	4.20	8.14
253	(7.91)	6.06	(1.71)	.64	(2413)	4370	(11.99)	0	.85	1.11
Region 1	13.90	40.77	4.29	8.91	10299	17755	26.31	35.0	4.52	8.14
41	(7.90)	6.06	(1.87)	1.17	(2248)	7465	(4.78)	18.4	(1.16)	1.11
Region 2	11.24	24.13	4.30	8.73	10741	28782	26.80	53.4	4.13	7.46
89	(3.66)	6.58	(1.97)	.64	(2606)	6654	(7.22)	11.3	(.72)	3.08
Region 3	11.85	44.73	4.28	8.32	8290	14537	30.14	59.7	3.96	6.84
40	(6.95)	6.79	(1.67)	1.47	(1599)	5737	(8.64)	18.5	.82	2.91
Region 4	14.95	23.83	4.18	7.60	9407	11437	15.51	27.1	4.21	7.68
16	(5.47)	7.52	(1.49)	1.12	(1035)	7476	(6.67)	7.5	(1.11)	2.94
Region 5	24.62	49.94	3.08	5.17	9995	15026	6.58	26.2	4.30	6.58
39	(6.96)	15.66	(.98)	1.12	(2205)	4370	(7.65)	0	(.80)	2.41
Region 6	22.27	36.27	3.57	5.61	11402	18208	11.93	49.5	4.07	5.19
28	(6.44)	9.94	(1.23)	1.36	(2304)	9898	(15.72)	0	(.50)	3.17

(continued)

Appendix Table 2. (Continued)

Region/City Size Number of Cities	Quantity per Meter (Q)		Price (P)		Median Income (Y)		Effective Rainfall (R)		Density (N)	
	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low	Mean (Std. Dev.)	High Low
Size of City:[†]										
Category 1	15.75	44.73	3.89	8.73	10464	28782	22.68	53.4	3.89	5.54
70	(8.72)	6.06	(1.62)	1.12	(3308)	4370	(12.11)	0	.57	2.41
Category 2	14.00	33.09	4.19	8.74	9914	19494	23.14	59.7	4.15	8.14
85	(6.46)	6.32	(1.87)	.64	(2226)	6030	(11.35)	0	.97	1.11
Category 3	16.00	39.42	3.99	8.91	10126	18208	19.11	55.2	4.29	7.68
65	(7.89)	6.79	(1.75)	1.61	(1843)	6452	(12.99)	0	(.80)	2.91
Category 4	16.17	49.94	3.91	7.14	10180	13183	21.56	44.0	4.73	6.60
33	(9.35)	7.86	(1.39)	2.07	(1450)	7737	(10.90)	0.5	(.87)	3.40

*See Figures 2 and 3, pp. 22 and 35, for regional delineations and names.

†See p. 24 for size-of-city categories.

Source: Data relating to quantity per meter, price and density are from *A Survey of Operating Data for Water Works in 1960* (American Water Works Association). Median income data are from *1960 Census of Population* (U.S. Dept. of Commerce). Effective rainfall data are from *Climatological Data for the United States* (U.S. Dept. of Commerce, U.S. Weather Bureau).

APPENDIX TABLE 3

CORRELATION MATRIX FOR VARIABLES IN EQUATION 1b, 1960 DATA*

	ln Q	P	ln Y	ln R	ln N	V_{01}	V_{02}	V_{03}	V_{04}	V_{05}	V_{06}	$V_{\rho 1}$	$V_{\rho 2}$	$V_{\rho 3}$	$V_{\rho 4}$	$V_{\rho 5}$	$V_{\rho 6}$
ln Q	1.00	-.59	.36	-.42	.19	-.14	-.28	-.19	.29	.46	.30	-.24	-.36	-.23	.20	.39	-.18
P		1.00	-.17	.12	-.02	.18	.01	-.11	-.15	-.13	-.16	.36	.38	.25	-.07	-.05	-.07
ln Y			1.00	-.16	.00	.14	.19	-.43	.04	-.03	.10	.05	.12	-.39	.04	-.05	.06
ln R				1.00	-.04	.15	.19	.20	-.15	-.40	-.33	.13	.16	.17	-.12	-.38	-.38
ln N					1.00	.06	-.14	.05	.03	.17	-.09	.01	-.11	.02	.05	.18	-.09
V_{01}						1.00	-.39	-.21	-.11	-.13	-.11	.90	-.33	-.20	-.10	-.12	-.10
V_{02}							1.00	-.44	-.22	-.27	-.23	-.35	.84	-.40	-.20	-.25	-.21
V_{03}								1.00	-.12	-.15	-.13	-.19	-.37	.92	-.11	-.14	-.12
V_{04}									1.00	-.07	-.06	-.09	-.18	-.11	.91	-.07	-.06
V_{05}										1.00	-.08	-.12	-.22	-.14	-.07	.93	-.07
V_{06}											1.00	-.10	-.20	-.12	-.06	-.07	.90
$V_{\rho 1}$												1.00	-.29	-.18	-.09	-.11	-.09
$V_{\rho 2}$													1.00	-.34	-.16	-.21	-.18
$V_{\rho 3}$														1.00	-.10	-.13	-.11
$V_{\rho 4}$															1.00	-.06	-.05
$V_{\rho 5}$																1.00	-.07
$V_{\rho 6}$																	1.00

*See pp. 18 and 19 for variable definitions.

APPENDIX TABLE 4

CORRELATION MATRIX FOR VARIABILES IN EQUATION 1b, 1970 DATA*

	ln Q	P	ln Y	ln R	ln N	V_{01}	V_{02}	V_{03}	V_{04}	V_{05}	V_{06}	$V_{\rho 1}$	$V_{\rho 2}$	$V_{\rho 3}$	$V_{\rho 4}$	$V_{\rho 5}$	$V_{\rho 6}$
ln Q	1.00	-.60	.25	-.57	.16	-.09	-.38	-.22	.01	.51	.34	-.20	-.44	-.28	-.03	.44	.27
P		1.00	-.11	.22	-.14	.07	.12	.07	.02	-.24	-.09	.25	.43	.21	.09	-.15	-.01
ln Y			1.00	-.22	.17	.04	.21	-.39	-.07	-.04	.20	.00	.12	-.35	-.08	-.06	.24
ln R				1.00	-.03	.19	.33	.23	.01	-.53	-.38	.18	.30	.20	.02	-.50	-.36
ln N					1.00	.13	-.03	-.12	0	.06	-.03	.03	-.05	-.13	-.02	.07	-.02
V_{01}						1.00	-.32	-.19	-.11	-.19	-.16	.90	-.28	-.18	-.11	-.18	-.15
V_{02}							1.00	-.32	-.19	-.31	-.26	-.29	.88	-.29	-.18	-.30	-.24
V_{03}								1.00	-.11	-.19	-.15	-.17	-.28	.92	-.11	-.17	-.14
V_{04}									1.00	-.11	-.09	-.10	-.17	-.10	.94	-.10	-.09
V_{05}										1.00	-.15	-.17	-.28	-.17	-.10	.95	-.14
V_{06}											1.00	-.14	-.23	-.14	-.09	-.14	.94
$V_{\rho 1}$												1.00	-.26	-.16	-.09	-.15	-.13
$V_{\rho 2}$													1.00	-.26	-.15	-.25	-.22
$V_{\rho 3}$														1.00	-.09	-.15	-.13
$V_{\rho 4}$															1.00	-.09	-.07
$V_{\rho 5}$																1.00	-.11
$V_{\rho 6}$																	1.00

*See pp. 18 and 19 for variable definitions.