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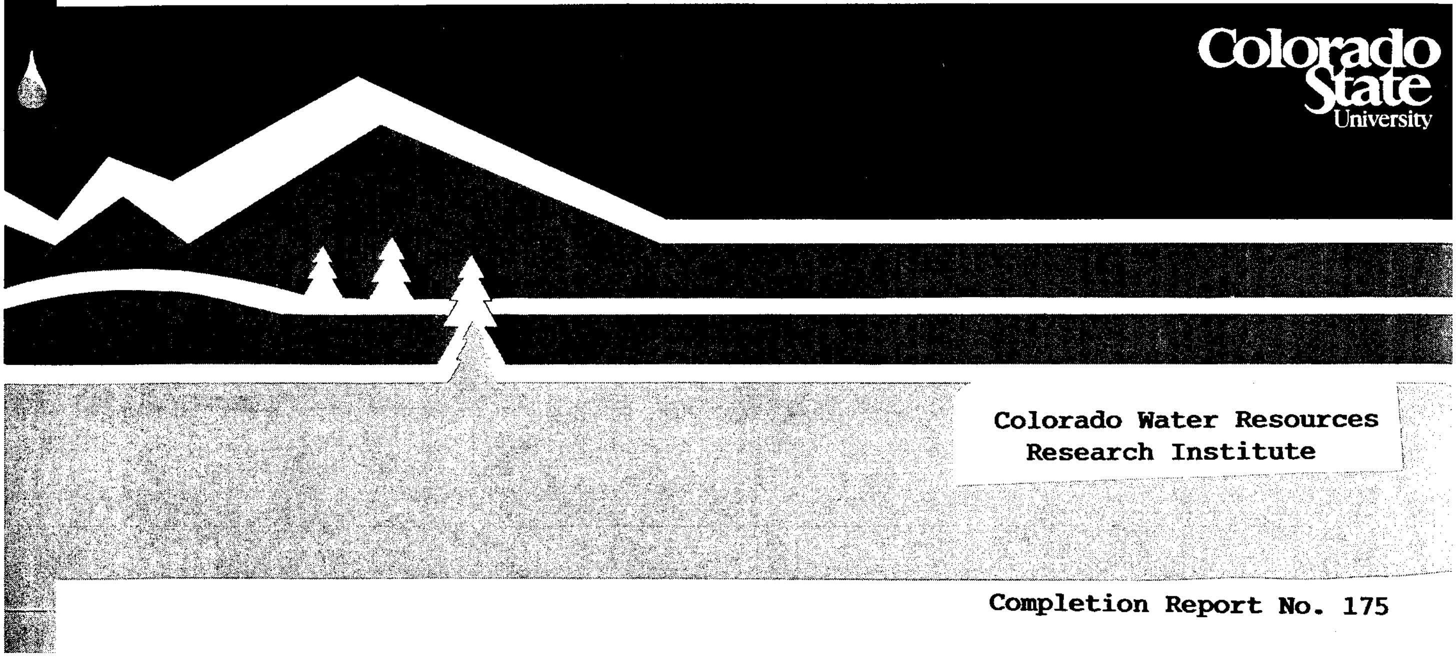

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ABSTRACT

This research undertook to study the economic and other factors affecting the demand for residential water in Colorado, with particular emphasis on the roles of metering and conservation programs for reducing water consumption. The study was motivated by the American Water Works Association's 1982 survey which reported that only about half of the Colorado water utilities used water meters, and evidence of higher use by nonmetered customers. We formulated a mail survey which requested 1985 and 1986 data on residential water use and on a range of factors hypothesized to affect water demand, including the levels and forms of water charges, the experience with conservation programs, frequency of billing and residents per connection. The survey responses were supplemented by federal government data on household income and on summer rainfall and temperature. In spite of repeated mailings and telephone requests, of the twenty eight utilities responding, only six were non-metered. Without meters, only water production data are available to represent water consumption. We contacted non-respondents in unmetered systems; they often told us that they lacked detailed records from which to fill out our questionnaire. With but two significant exceptions, nonmetered utilities tended to be those serving but a few customers and to be located where water was plentiful and inexpensive. Several respondents reported that they were in process of converting to meters or had recently done so. It appears that metering residential water use is no longer a major potential source of reduced residential water use in Colorado.

The two years of data for all respondents were pooled and statistical regression analysis was applied to test the hypothesis that annual residential water use could be explained by the following variables: marginal and average cost of water, average family income, summer temperature and rainfall, density (persons per household), frequency of billing and the presence of conservation education programs. Of the several functional forms tested, linear and semi-log forms provided the most satisfactory fit to the data. Water changes were found to have a negative and statistically significant effect on water use. However, the presence of a conservation education program exhibited no statistically significant influence on water use. The equations using average price explained the data somewhat better than did marginal price formulations. (At the mean of the observations, price elasticity of demand for metered water was found to be about -0.4, quite similar to that reported for other regions of the U.S.) Somewhat surprisingly, a strong negative association was found also between cost of water and water use for the non-metered subsample, although the limited sample size cautions against generalizations from this finding. Also of interest was that more frequent billings reduce water use. (The above findings, taken together, show that cost does negatively influence water use, but that the residential water user departs somewhat from textbook model of the fully informed consumer who precisely responds to marginal price). Household size, as expected, positively influenced water consumption. Weather variables also showed impacts in the expected directions, although the associations were not particularly strong. However, household income was not found to be a statistically significant influence on average water use.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Throughout much of the western United States, water continues to be a prominent policy issue. This comes about because water, at its current price level and within the present political infrastructure, is being demanded in quantities greater than can be supplied. Competing interests exist between municipal and agricultural demands, upstream and downstream users, and instream flow considerations versus offstream diversion requirements, making water a scarce resource indeed.

In order to properly satisfy the competing uses for water, the resource must be allocated efficiently. Economic theory implies that when the free market functions correctly, resources are optimally allocated to the different competing demands. Economic efficiency results when water is supplied in quantities such that the marginal price charged for water is equal to the marginal cost to provide it. However, in today's market, certain characteristics of the production and sale of water prevent an optimal and efficient distribution. One example occurs when water is not priced according to the quantity consumed so that its marginal price to the user is equal to zero. This is called flat rate pricing and occurs when water meters and a volumetric pricing schedule are absent. A customer of a nonmetered system will pay a flat-rate charge every billing period regardless of how little or how much water is consumed. Contrast this situation to a metered system where water is priced at the margin (marginal price greater than zero), and the total water bill is at least partially determined by the quantity of water consumed as a function of the consumer's water demand behavior.

Despite the inherent common sense appeal of a metered system for efficiency, equity and accounting reasons, some municipalities in Colorado and elsewhere in the west still support a nonmetered water system. And, in spite of the need to better understand the variables that influence water demand, very few studies exist that have actually compared any differences that may exist between metered and nonmetered water systems and their demand for water.

Objectives and Procedures

The purpose of this study is to measure the residential demand for water in Colorado, and particularly to examine possible differences in demand behavior between metered and non-metered water users. And, if differences do exist, to determine what variables affect the different demands for water.

Data used in this study were collected by a questionnaire sent to water managers throughout Colorado requesting information on the consumptive use of water for two years, 1984 and 1985. The United States 1980 Census Data for Colorado provided data for income and population figures as needed, while the Climatological Data Annual Summary for 1984 and 1985 was consulted for the appropriate weather data. Statistical regression analysis was employed to measure the effects of various factors on water use.

Characteristics of Water

Our use and valuation of water reflect a host of contradictions. On the one hand, we herald water's almost sacred, life giving properties, while on the other hand, we price it so low that there is little if any incentive to conserve it. Recent controversies concerning the allocation of water suggests an increasing degree of scarcity as an economic resource. Yet, we seem unwilling to change our modes of consumption to comply with this inferred scarcity. These social and economic incongruities exist, in part, because of several characteristics inherent in water that impart an elusive nature to the resource.

Transient

Water, by its physical nature, is constantly changing. It can appear in three different physical states: solid, liquid, and gaseous. Consequently, it moves from one location to another and from one form to another as the physical state, quantity, and quality are transformed. Variables that affect the transitory nature of water are oftentimes transient themselves: rainfall, sunshine, and evaporation rates.

Recyclable

Water is a renewable resource and can be reused or recycled on several different levels. On the local level, water can be reused within and/or between communities. Treated residential sewage can be reused by agriculture, industry, public authority, or even resident users again for sprinkling and irrigation purposes. (It can be reused for domestic demand if the treatment technology is appropriately sophisticated and if the community attitudes are accepting enough.) If the geographical boundaries are extended, water is observed being recycled between upstream and downstream users. An upstream user returns a portion of diverted water back into the system for downstream users who return a portion of water back into the system for further downstream users as the cycle continues to repeat itself. For example, in the South Platte River Basin of Colorado, " . . . the total annual volume of water withdrawn for use in the basin ranges from 2 to 2.5 times the annual native supply."[1]

Extending further beyond state boundaries, one can observe whole hydrologic basins such as the Colorado River Basin which includes six states. On this level, the social value derived from this recyclable property is enormous. Of course, the proportion of water diverted and returned to the system will vary across space, time, and medium. Water initially diverted from groundwater may be returned to a surface stream and then evaporated into the atmosphere. And lastly, water on a global scale is constantly being recycled and redistributed through atmospheric, surface, and underground sources of water.

Competing Uses

Because of water's transient qualities and apparent ignorance of man-made boundaries, water does not lend itself to well defined property rights the way other resources do in terms of finite, measurable, and stationary quantities. Therefore, the potential for conflict for competing uses is greater than with other economic resources. Competition for water exists between downstream and upstream users, municipal and agricultural demands, recreation and urban, and instream flow considerations and diversion projects. Competing uses for water also infer competing degrees of the quality of water.

Universal Solvent

Water has widespread application as a solvent for assimilating pollutants and waste. Because of its capacity for absorbing and transporting wastes and toxins, questions of water quality are especially relevant.

Bulkiness

Water is an example of what economists call bulky economic goods. Relative to other consumer goods, the price per unit of water consumed at the margin is very low even though its total aggregate value may be very high. Consequently, we do not think of water in the same way that we think of other economic goods and the finite value we derive from their consumption. Rather, we associate certain tangibles and intangibles that we perceive water to provide for us: a non-native, water loving landscape in a semi arid region, convenience appliances such as dishwashers and washing machines, status, recreation, time, and money. And if water is priced artificially low, an unrealistically high value will be placed on cheap water and the amenities it can provide. As Milliman (1963) comments,

> Clearly, our tastes for outdoor landscaping have been conditioned by a long heritage of cheap water supplies and subsidies on peak use. There exists a whole range of landscaping alternatives which could be adapted to a water scarce urban environment.[2]

The Water Industry

Possibly as a consequence of these aforementioned traits associated with water, or maybe in spite of them, the water industry has evolved its own set of distinguishing characteristics which has shaped the distribution and pricing of water. One of the most consistent features of the water industry is the dominance of public ownership. Most water providing entities that serve municipalities are publicly or semi-publicly owned. This situation can be attributed to several reasons:

Water is Different

Water is perceived to be different from other economic goods whose quantities and prices are determined by the market. Water is considered such a critical life force that it cannot be trusted to the private sector. (This may be more strongly ingrained in the minds of water managers than the public.) Young and Haveman (1985) quote Boulding to underscore this point, "The sacredness of water as a symbol of ritual purity exempts it in some degree from the dirty rationality of the market."[3]

Control

In the arid west, especially, water availability could single-handedly determine the economic fate and direction of a region or town. Acting as a representative for the collective good, a municipally governed water system would have legitimacy in the public eye as well as greater political and legal power.

Financial Requirements

Water supply projects are long-lived and capital-intensive. They require a great deal of financial backing which municipalities can often provide with their ready access to such mechanisms as low-interest bonds, taxation, government assistance, and powers of condemnation.

Economies of Scale

Water projects are often characterized by economies to scale or decreasing costs, a situation commonly associated with monopolies. This raises questions of equity and fairness since an efficient pricing scheme is not readily determined in the market place. Politically, this situation is more easily accepted if the controlling entity is publicly owned rather than privately owned.

Another trait (and point of criticism of the water industry) is its "resistance to change." Early critics have pointed to its longstanding reliance on a financial criteria for pricing and planning rather than an economic one. Milliman (1963) suggests that one reason for the industry's reluctance to switch to an economic decision criteria is the technological stagnation that has shaped the industry's approach to dealing with water. Excluding treatment technology, the manner in which water is impounded, transported, and distributed has remained relatively constant since Roman times.[4] Consequently, the water industry has evolved with an emphasis on dealing with water issues through "structural means" rather than developing or emphasizing nonstructural mechanisms of dealing with water issues such as pricing, conservation, or water right exchanges. This has resulted in the entrenchment of institutional and attitudinal barriers to change in dealing with water.

The emphasis on dealing with water issues via structural means has been encouraged by the longstanding existence of very low water costs. For many years, the costs of providing water were very low in comparison to the total aggregate value derived from its end uses. Consequently, municipalities usually adopted a pricing scheme that did not reflect the marginal cost of supplying water. More commonly, the price of water was set to equal historical average total costs. The existence of very low water prices was due in part to economies of scale resulting from large water projects which in turn, encouraged large water projects to be built. A common pricing practice under conditions of inexpensive water was a declining block rate structure. This faced the consumer with a lower, marginal price as consumption increased. Of course, sometimes the price for water was set to meet some other agenda. For example, it is still a common practice of cities to charge a low price for water in order to attract residential, industrial, and commercial growth.

The emphasis on dealing with water issues by structural means is illustrated by observing how a water system is designed to meet different demands. One such description for a typical urban water system is provided by Howe and Linaweaver (1967). Generally, there are three different measures of water demand that a system must consider: average annual demand, maximum day demands, and peak hour demands or maximum day plus fire flow (whichever is greater). Consequently, there exist three different components of the water system that are designed to meet these different demands. These are, respectively: basic sources; transmission and treatment facilities, distribution pumping stations, and major feeder mains; and local distribution mains, connections, and local storage. (These different components might roughly account for 30%, 20%, and 50% respectively of total system investment.)[5]

> Thus two systems experiencing equal average annual demands would be designed differently if their peak demand patterns differed. That a large portion of system investment may be keyed to maximum day and peak hour demands serves to point up the importance of differences exhibited in demand behavior between metered and flat-rate areas . . .[6]

When Howe and Linaweaver made this comment in 1967, forecasting water demand for purposes of system design consisted of applying peak-to-average ratios to a total city average daily per capita use figure. Peak-to-average ratios released by the Federal Housing Administration in 1965 prompted this comment from Howe and Linaweaver:

> In the absence of reliable records, an average demand of 100 gallons per capita per day and 4 persons per dwelling unit should be used. A maximum daily demand of 200% of average and peak hourly demand of 500% of average are suggested, except for areas where 'extensive lawn irrigation is practiced,' when

> 700% of average for peak hour rates is recommended. The Residential Water Use Research Project at Johns Hopkins University concluded that these criteria can lead to substantial over or under-design of systems. Clearly they contain no allowance for climate, economic level, price, and other effects. In the 39 residential study areas used in this study, average annual use per capita ranged from 47 gpcd to 437 gpcd. Persons per dwelling unit ranged from 1.8 to 4.9, the maximum day to average ratio ranged from 157% to 541% and peak hour to average from 247% to 1650%.[7]

One other reason that has been cited for the water industry's resistance to change is that until recently, water projects were not very controversial and did not enter the public arena very often. Since they were absent from the public eye, there was little public input or objection to proposed water projects.[8] Certainly, with our society's growing environmental consciousness, large water supply projects like the proposed Two Forks Dam on the upper South Platte River can no longer escape public scrutiny.

CHAPTER II

LITERATURE REVIEW

Introduction

Early water studies were based on a "requirements" concept that assumed the demand for water to be a function of only two variables: population and the type of industrial development present. And because this period of time was characterized by water supply projects with economies of scale, modest levels of water demand, and low rates of inflation, there was little need to question this approach. Consequently, traditional economic factors such as price, income, tastes, and availability and pricing of substitute and complementary goods were not considered relevant and were treated as constants in the demand for water (Foster and Beattie, 1979).

Wong (1972) observed four "complexities" associated with economic studies that may have acted as a barrier to abandoning the requirements approach for studying water demand. these complexities still exist today:

(1) Water consumption data are oftentimes unreliable. Because water has been so inexpensive, there has been little incentive for water providers to keep strict records of water consumption. And, even when meters have been present, consumption figures are often only a rough estimate. This situation is reflected by the common practice of aggregating consumption data of the different user classes (residential, commercial, etc.).

(2) No standard pricing policy is adhered to by public water providers. This may be the case between user classes within a single community as well as between different communities. One user class may be nonmetered and charged with flat-rate pricing (e.g. residential) while another user class may be metered and face a multi-part tariff, either decreasing or increasing.

Some communities have their sewage charge included in their price for water, others have it charged separately. Oftentimes, sewage charges may be only minimally related to the quantity of water consumed. Variation in the frequency of billing only compounds the situation. This omnipresence of inconsistency in pricing led one reviewer to quip, "that municipal water rates are 'the most unscientifically determined price in the public utility field.'"[9]

(3) Appropriate income data can be difficult to obtain. Because water is a normal good, economic theory dictates that income should be relevant in influencing the demand for water. However, appropriate and reliable income data is not easily secured. Several of the more recent water studies using income as an explanatory variable have shown it to be insignificant. This may occur in part, because of the lack of variability often found in available income data. Attempts to circumvent this problem by using proxies for income such as house value, sales tax, and number of bathrooms, etc. often result in a high degree of correlation when included together in the same model. Yet, exclusion of the income effect from the model may result in model error.

(4) Sufficiently large data sample sets may not be available. Due to the difficultly of securing an ideal data set, sample reliability may be compromised. For time series analysis, the time period may be too short and for cross-sectional data, the sample size may be too small. Using pooled data (combining cross-sectional and time series) will provide for a larger data set, but introduces other statistical challenges that must be addressed.[10]

The above-mentioned difficulties still exist today and produce their share of challenges for researchers. Therefore, it is understandable that Wong expressed little surprise at the dearth of <u>economic</u> studies on the demand for water up through the early 1970's. However, as easy and cheap sources of water have become increasingly scarce, the need for a better understanding of the forces affecting water demand has provided the impetus for a change from the strict "requirements" approach to incorporating an "economics" approach.

The Economics Approach

Initially, some of the newer breed of water studies evaluated both metered and nonmetered data. Howe and Linaweaver (1965) conducted a study that included eight non-metered (flatrate, public water) municipalities along with several metered municipalities from across the country. They found that the nonmetered communities responded to fewer variables than did metered communities. For domestic demand, nonmetered areas were influenced only by the market value of the house and the number of persons per dwelling unit. For summer sprinkling demand, only the market value of house influenced water consumption. Maximum day sprinkling demand was affected by the market value of house and irrigable area per dwelling unit. In comparison, variables shown to influence the demand for water by metered areas also included: the market value of the dwelling unit, age of the dwelling unit, the price of water that varied with quantity consumed, marginal commodity charge, climate, and income. Their analysis indicated that after controlling for these variables, nonmetered residents consumed an average 692 gallons (of water) per day per dwelling, while the metered residents consumed an average 458 gallons (of water) per day per dwelling.

Hanke (1969) utilized time series data for Boulder, Colorado to demonstrate that water users consumed less water under a metered system than they did under a nonmetered system for both domestic and sprinkling needs. For the years 1956 to 1968, Hanke determined that a change from flat rate pricing to a positive, incremental charge resulted in significant changes in behavior for water demand. The level of domestic consumption dropped by 36% the first year metering was employed and remained stable at that reduced level. The level of the sprinkling demand declined as well from earlier, nonmetered levels. In addition, Hanke found both an increasing price elasticity and a decreasing income elasticity for water over time. However, the results could not support the a priori hypothesis that the rate of demand for water would decline as did the total quantity of water demanded. That is, consumers did not appear to change their rate of demand for water, but rather, only their total demand for water. Graphically, this is illustrated only by a parallel shift downward in the demand curve rather than an additional change in the slope (i.e. rate of change) of the demand curve.

Hanke (1971) conducted a follow up study which consisted of interviews of residents utilized in the first study. The results of his second study supported the conclusions drawn in the first study: that people became more aware of the quantity of water they consumed when under a metered system. Consequently, the reduced demand for water remained stable and did not climb back up to former levels associated with the earlier nonmetered system.

After the studies conducted by Howe and Linaweaver and Hanke, most other studies relied primarily on metered data. The reasons for this may be twofold:

(1) As water became more expensive to supply, and water providers felt the need to better account for their water, switching to a metered system was a natural progression. Consequently, nonmetered data were not so readily available. (However, it should be noted that in the American Water Works Association 1982 Utility Report, about half of the utilities reported for Colorado were nonmetered.)[11] and,

(2) Because an accurate measuring mechanism does not exist within a nonmetered system, reliable and accurate data are difficult to obtain for nonmetered water consumption. Consequently, most studies would naturally seek out the more accurate data that can be obtained from metered water systems.

Because of the dominant use of metered data, most analysis has been restricted to studying variables that affect the demand for metered water. Gardner and Schick (1963) examined cross-sectional, annual data for northern Utah and found average price and lot size (for irrigation purposes) to exert the most influence on water demand. Young (1973) evaluated annual, time series data for Tucson, Arizona and found the demand for water to be influenced by average price and rainfall. In both studies attempts were made to include income or a proxy for income, but the results showed the coefficients for the variable to be insignificant.

Wong (1972) conducted a bipartite study of Chicago, Illinois and the surrounding communities utilizing a time series model. For the bedroom communities of Chicago, the marginal price of water was significant in explaining the demand for water but not so for the city of Chicago. Wong suggests this difference may be partially explained by the <u>extremely</u> low water prices faced by Chicago relative to her surrounding communities and the fact that much of Chicago was not metered. However, income was found to influence water demand in Chicago but <u>not</u> in the surrounding communities. Other variables found to influence the demand for water for both Chicago and her surrounding areas were average household income and the average summer temperature.

In the second part of the study, Wong looked at crosssectional data for 103 surrounding, municipal water systems which relied exclusively on groundwater in contrast to Chicago and her suburbs that relied strictly on surface water from Lake Michigan. In the cross-sectional analysis, income was statistically significant for the two larger sized community groups. Price was significant for <u>all</u> but the smallest sized community group. Average summer temperature was not included because there was little variation. Despite the significance of the aforementioned variables, the degree of variation explained by these variables was rather low. The coefficient of determination, R^2, ranged from 0.29 to 0.48.

Danielson (1979) utilized pooled data at the household level to estimate the effect of several variables on total residential demand, sprinkling demand, and winter demand for Raleigh, North Carolina. His results showed average rainfall, average temperature, house value (as a proxy for income), marginal price and household size all influenced the total residential demand for water. Household size explained more variation in the total demand for water than any other variable. For winter demand, (total minus summer), house value, the marginal price charged for water, and household size influenced water demand. For summer sprinkling demand, average rainfall, average temperature, house value, and water price were significant.

Foster and Beattie (1979) developed a "generalized model allowing for categorical effects due to regional and size of city differences on urban residential water demand."[12] They found municipal (residential) water demand to be a function of the median household income, rainfall during the growing season, average number of residents per meter, the average price of water, and a subregional dummy variable. (They divided the U.S. into six subregions to pick up regional differences.)

Hansen and Narayanan (1981) utilized monthly time series data for municipal water use in Salt Lake City, Utah. Their estimated model indicated that the price of water, total rainfall, average temperature, number of daylight hours, and a non-growing season dummy variable were significant in explaining the average monthly demand for water per household.

Hanke and de Mare (1982) conducted a study on water demand for Malmo, Sweden. One emphasis of their study was to secure data which was not plagued by the types of biases and problems often found in aggregated data. Variables found to influence the semi-annual residential demand for water were: real gross income per household, number of adults, number of children, rainfall, the age of the house, and the real marginal price of water.

Frerichs, Becker, and Easter (1987) studied municipal water data for cities and communities in Minnesota. They found the demand for water to be influenced by marginal price, average price (separate models), income, number of persons per household, and the proportion of youth per household (assuming that even though someone under 18 years of age may have less awareness to conserve water, an adult will use more water). A dummy variable to pick up differences in demand between different sized cities proved insignificant, even though the proportion of variation in the model(s) was better explained for larger cities than for smaller ones.

Dellenbarger, Kang and Schreiner (1988) studied differences in water demand behavior between urban and rural residents in Oklahoma. Hypothesizing that rural households have more uses for water but also more alternative supply sources (e.g. private wells or other irrigation services), they expected rural water users to exhibit a more price elastic response to water demand than their urban counterparts. Variables shown to influence the rural demand for water were: marginal price, annual household income, number of persons per household, a dummy variable to capture the increased demand during the growing season, and urban or rural water user status.

The Price Variable

As mentioned earlier, a number of alternative pricing mechanisms exist within the water industry. However, the industry as a whole is faced with meeting similar financial objectives and overhead costs. Therefore, most metered utilities have a flat rate service charge combined with some type of commodity charge based on the incremental consumption of water. The situation becomes more complex if the pricing schedule is a multi-part tariff versus one of constant pricing per unit of consumption. Multi-part tariffs can be increasing or decreasing depending upon the policy of the water utility. When water was very inexpensive, declining block rate structures were very common so that the more water the customer demanded, the lower was the marginal price paid. How such rate structure complexities affect the consumer's perception of the price he pays for water is difficult to say.

Except for a discussion on the preferred use of marginal price in the John Hopkins study by Howe and Linaweaver (1967), the question of an appropriate price variable was not extensively discussed in the literature until the late 1970's. Prior to that time, many studies used either average price, marginal price, or simply did not specify what form of price was being used.

Foster and Beattie (1979) used average price per 1000 gallons as the price variable. (They did acknowledge the potential for a simultaneity problem with aggregated data, but felt it was unavoidable but manageable.) This initiated a flurry of articles addressing the question of the proper price variable. In response to Foster and Beattie's (1979) study, Griffin, Martin and Wade (1981) criticized their choice of average price for several reasons. However, the criticism that has drawn the most attention is their concern that the use of average price, " . . . at low levels of consumption, . . . is not closely related to the marginal price faced by consumers . . ."[13]

The critics argue that marginal price is the preferred price variable because it is consistent with consumer demand theory in terms of consumers wanting to maximize their utility at the margin. Consequently, using average price will produce unreliable results in "predicting the effect of price on water demand"[14] by overestimating the relationship between changes in price and the demand for water.

Billings and Agthe (1981) criticized the use of average price in earlier studies in general. They argued that average price is not the marginal price except in special cases and suggest the use of a two-part price variable designed to accommodate both the price and income effects present with multi-part tariffs, especially those with a declining block structure. The two-part price variable model suggested by Billings and Agthe (1981) was first proposed by Taylor (1975) for electricity demand and later modified by Nordin (1976).

In response, Foster and Beattie (1981) defend their choice of average price as the appropriate price variable because of a breakdown in one of the required conditions necessary for preferring marginal priced. In quoting Taylor who quotes Anderson,

> The correct price variable to appear . . . for these commodities is, therefore, not the average unit price but the price of a marginal unit of consumption, <u>provided that consumers are well informed</u> (emphasis ours).[15]

They wonder how many water consumers are aware of their true, marginal price given the complexities surrounding the typical water bill, such as time constraints facing consumers, seasonal differences, the combining of sewer charges with water, etc. Rather, they suggest ". . . .it is probable that most residential water consumers, not just minimum block users, perceive their total expenditure function as a ray line."[16] Since this expenditure function extends outward from the origin, average price and marginal price are the same. The average price of water is perceived by the consumer to be the marginal price for water. Foster and Beattie offer this reasoning to explain why consumers facing a fixed charge block behave as if they are facing a variable charge block (Danielson 1977).

Besides the commonsense appeal of their argument, additional support is lent to Foster and Beattie's position by the lack of decisive empirical support for the superiority of the other proposed price variables. Studies that have utilized the two part price variable have failed to produce superior results to their average price counterparts. This includes both the explanatory power of the estimated model(s) in addition to the degree of statistical significance of the coefficients for price and other explanatory variables. Most of these studies do find marginal price to be significant in explaining water demand. However, whereas the difference variable chosen to pick up the income effect resulting from intramarginal charges is oftentimes the right sign and statistically significant, not one study has shown it to be equal in magnitude to the income variable as postulated by economic theory. (It is always smaller in magnitude.)

The consistent unruliness of the (income) difference variable may be explained by the very low income effect resulting from the inframarginal charges in a declining block structure. For residential water, it constitutes such a small percentage of total income, that the income effect resulting from changes in the inframarginal charges may be negligible in the mind of the consumer.

Chicoine, Deller, and Ramamurthy (1986) developed a water demand model for testing alternative price variable specifications. One of their conclusions was, " The Taylor Nordin specification of demand for goods sold under block rate pricing schedules may not always be the best description or representation of consumer behavior."[17] Boland et al (1984) reported a comprehensive comparison of water studies to evaluate the effect of price and rate structure on municipal and industrial water demand. When comparing the differences between using marginal price and average price, they concluded, " . . . it is not clear that average price is inferior to marginal price as an estimator of customer perception price, economic theory notwithstanding . . . "[18] because of such variables as complexities of rate schedules and time lags in the billing frequency.

Another related controversy in water demand studies concerns what the proper statistical methodology should be. Studies that are concerned with problems of simultaneity bias arising from the presence of block rate structures have utilized two and three-stage-least squares regression in an attempt to counter possible errors resulting from simultaneity bias. However, it is not clear from the results that the more sophisticated approaches are any better in predicting water demand. Chicoine et al (1986) concluded that,

> The similarity between three-staged-least squares and single equation ordinary least squares estimates provides some validation for the use of simpler single equation demand models of potable water when water is sold in block rate pricing schedules.[19]

In addition to controversies concerning the proper price variable and statistical methodology, disagreement also exists over the proper functional form. Of course this may vary depending on the purpose of the study, but researchers have lamented the absence of a definitive link between theory and a preferred functional form for water demand models.[20] Different forms have been hypothesized as preferable for different reasons (Foster and Beattie, 1982; Plourde and Ryan, 1986). Each functional form reflects different expectations for utility maximization and price and income elasticities, but explanations and results have not been conclusive. And despite some of the elegant discussions for or against a particular functional form, no one form has distinguished itself in residential water demand studies. The simpler, single equation models using linear, double-log, and mixed-log functions have been commonly used in residential water demand studies and have produced comparable (if not more robust) results than some of the more sophisticated functional forms.

The absence of any one functional form, regression model, or price variable dominating the study of water in terms of producing superior results may be indicative of the wide range of dynamics that can affect water demand and the problems in trying to model for it. To expect that one particular price variable or statistical approach should be preferred, no matter what the situation, may be unrealistic and may act as a barrier to a greater understanding of the demand for water. And though there are common patterns of behavior that emerge throughout water studies, there is also a great deal of variation and inconsistency among those same studies. In light of such variable parameters as consumer perception, cultural differences, availability and reliability of data, and external forces (e.g. weather patterns), it may be unrealistic to expect to be able to model for local demand from a national or even regional perspective for anything but a general trend or pattern. Realizing the importance of local conditions in water demand studies should allow for the development and acceptance of a wide range of relevant models.

CHAPTER III

MODEL SPECIFICATION AND DATA SOURCES

Introduction

This chapter addresses considerations relating to model specification and data sources. In particular, five general areas are discussed:

(1) Neoclassical theory applied to the residential demand for water. Relevant factors of demand include traditional variables such as price, income, and substitute and complementary goods as well as,

(2) Other variables affecting the demand for residential water such as weather, cultural values, and consumer perception.

(3) The design of the survey and, in addition, the collected data set.

(4) Hypothesized models and preliminary results.

(5) Simple descriptive statistics of the data set.

Neoclassical Theory Applied to Residential Water Demand

According to the neoclassical theory of consumer demand, consumption of a good or service is largely influenced by four different factors: the price of the good being demanded income of the prospective purchaser, the price of related goods (complements and substitutes), and tastes or preferences. But the degree of influence these variables exert on the demand for water will vary across space and time due in part to such factors as available information, perceptions, cultural biases, and climate.

The demand for a normal good moves inversely to its price. The higher the cost, the smaller the quantity that will be demanded, ceteris paribus. The extent of influence that price will have on the demand for water will depend partially upon people's perception of price and the relative proportion of total income that is allocated to pay for water. Agreeing with the logic and reasons supplied by Foster and Beattie (1981), average price is chosen as the preferred price variable for explaining the demand for water in this study. It is postulated that people perceive the average price they pay for water to be their marginal price.

Strongly linked to the influence price can exert on demand is the proportion of total income allocated to pay for an economic good. If the good is needed only in small quantities and/or infrequently, a high marginal price may be more acceptable. However, if the good is desired in large quantities and/or its expenditures require a large proportion of available income, then a high marginal price will exert a more profound impact on demand. Traditionally, water has been priced very low with total expenditures being quite low. In these lower price ranges, an inelastic response to changes in price has been observed. This situation should not be interpreted as reflecting some inherently high value for water at a very low price level. Rather, the inelastic response may be indicative of the small impact water purchases have on total income at these low price levels.

If the proportion of income allocated to water is high enough, and if changes in people's water demand behavior can affect that proportion, then the price for water will exert a strong impact on the demand for water. For example, the greater the proportion of the total water bill determined by marginal consumption, the more freedom the consumer has in determining her/his total water bill. A total water bill with a flat-rate service charge that accounts for 30% of an average total bill will allow the consumer to affect her/his total water bill to a greater extent than the consumer with a flat-rate service charge that accounts for 60% of an average total bill. And the greater the share of his/her income that goes to paying the water bill, the greater the incentive to reduce that water bill.

Cross-price effects or the price of substitute and complementary goods are also expected to affect the demand for water. Foster and Beattie (1979) argued that water has no real substitutes so that cross-price effects are negligible. Certainly, for the basic, life sustaining requirements, there truly may not be any substitutes. But the percentage of total water demanded for this need is small, so it is difficult to imagine that viable substitutes do not exist for many of the other uses of water. Rather, the price of water has been so low, that there has been little reason to seek out substitute goods.

Certainly, the availability of alternative water sources will affect the demand for substitute goods for water. The most common uses of water for family and commercial purposes can be divided into domestic uses (indoor uses such as drinking, cooking, washing, etc.) and outdoor uses (for example, sprinkling demand, swimming pools, or car washing) and are usually provided by the same water source. Since most municipal serving water suppliers are controlled by some government or quasi-government entity, consumers (especially urban) are limited in their access to alternative water supplies. For non-urban demands, private wells are very common in rural areas where groundwater supplies are accessible within a reasonable price range. In other situations, water is hauled by truck. But these are not considered preferable in urban areas, and as long as water is relatively inexpensive and of good quality, there has been little reason for consumers to seek alternatives to municipally supplied water. However, the situation is beginning to change.

With growing concerns surrounding water quality, an increasing number of homes and businesses are buying bottled water for drinking and cooking purposes. And although this accounts for a very small percentage of total water demanded, it is a substitute good.

Another substitute good for water which may have much wider application is increased technical efficiency, where capital and improved technology of water use is being substituted for increased water demand and consequently, increased water supplies.[24] Technologically, greater efficiency can be obtained with the installation of such devices as low flush toilets, low use showerheads, automatic sprinkling systems, leak detection devices, and more efficiently designed convenience appliances (for example, dishwashers and washing machines).

Behavioral changes that can substitute for increased water demand include: using water-efficient products, substituting water-thrifty grasses and plant species for water loving grasses and plants in lawns and yards, greater awareness of watering needs, adjusting water schedules to maximize plant assimilation and minimize peak demand, reduction of irrigable lawn and yard areas, and voluntary rationing.

When water is inexpensive relative to other goods, there is little incentive to make substitutions for water. But, when the price of water increases enough to force a comparison of the relative value of goods, substitutes for water that did not exist with cheaper water begin to emerge and develop.

At present, water is still inexpensive enough that the demand for these substitute goods is relatively low. Consequently, the cross-price effects appear to be small, though on a local level they have the potential to be significant. In time, as the price of water continues to increase, the cross-price effects of these substitute goods will affect the demand for water.

However, for this study, it is assumed that cross-price effects of substitute goods are still negligible.

Along with the price of substitute goods that determine the demand for water, is the price of complementary goods. Many complementary goods are convenience-saving, water-using appliances that are one time expenses. The price effects of these durable goods are also assumed to be negligible.

Another set of dynamics that can affect water demand relates to tastes and preferences. If attitudes toward resource conservation change, water-saving devices and behavior will be more readily accepted and used. Of course, different tastes or preferences can work in different directions. A society with increasing emphasis on recreation may place an increasing demand on water resources of all types: irrigation for golf courses and parks, swimming pools, boating and lakes, and fishing and free flowing streams. And, though these different activities may compete against one another for available water, they should also work together to promote greater conservation in order to expand water supplies in general.

Additional Factors Affecting Residential Water Demand

Other variables that are expected to influence the demand for water include weather variables, billing procedures instituted by the water utility, water conservation programs, and the number of persons per household. Because metered and nonmetered water users face a positive and zero marginal price respectively, it is hypothesized that they will respond in different degrees to some variables: average maximum daily summer temperature, average total monthly rainfall, and the existence and duration of a conservation program.

Without an increasing incremental cost, as the maximum daily summer temperature rises, nonmetered consumers will be expected to water more frequently and for a longer duration than metered consumers. That is, the metered group will be more discriminating in responding to temperature because of the increased marginal cost. This same reasoning can be applied to precipitation and its impact on the sprinkling demand. Both metered and nonmetered customers are hypothesized to be influenced inversely by the amount of precipitation received during the summer months, but metered will be more discriminating in their water demand. It is expected that their demand for water will not increase as much in response to increases in temperature or insufficient precipitation.

A similar but reversed response between metered and nonmetered customers may also be observed with regards to the existence and duration of a conservation program. For metered customers, the presence of a positive marginal price can act as a natural water conservation mechanism. Hence, the implementation of a conservation program may not be as effective because the presence of a positive marginal price has already precipitated a reduced demand for water. But, since nonmetered customers have no positive marginal price to induce them to conserve, the implementation of an intelligently-conceived conservation program would be expected to have a greater impact on reducing nonmetered water demand than on metered demand. Of course, the success of such a program would depend upon such variables as the customer's perception of the need for the program, the incidence of burden, the perceived effectiveness of the program, and commitment by the administering water utility.

Responses collected in this study revealed a wide spectrum of conservation measures, enforcement policies, and level of commitment by water providers. Because of the difficulty in trying to quantify such a diverse variable as "conservation efforts," and because the length of time used in the study did not allow for the testing of a trend variable for conservation efforts and attitudes, it was decided that the most reasonable measure of the possible impact of a conservation program was to denote (with a dummy variable) whether a program existed and the number of years it had been in existence.

A variable hypothesized to affect only metered customers is the frequency of billing (one, two, or three for the number of months between billings). The more frequent the billing process, the greater the link is between water consumed and money paid. The higher the associated cost of water is, the less water that is expected to be demanded in the next billing period. Nonmetered users are not expected to be affected by the frequency of billing since their water bill is constant regardless of consumption.

The number of persons per dwelling ("density") is hypothesized to influence both metered and nonmetered consumers. As density increases, the demand for water can be anticipated to increase. It is difficult to say, a priori, whether metered and nonmetered water users should respond differently in degree to density.

The Data Set and Surveys

Initially, the hypothesized models describing differences in water demand between metered and nonmetered customers were tested using data from communities in Colorado presented in the American Water Works Association's (AWWA) Annual Utility Reporting Data, 1980. This publication listed data by state that was received from AWWA member throughout the United States.

Our initial analysis indicated a significant difference of the mean water use groups between the two groups; (metered and nonmetered). However, more elaborate analysis failed to yield reliable generalizations regarding factors hypothesized to influence water demand. Later, it became apparent that the typical format of collection report to AWWA did not yield sufficient data for analyzing water demand for single family residential water demand.

Therefore, in 1986 a mail survey was initiated which contacted municipal water providers in six southwestern states: Colorado, Utah, New Mexico, Arizona, Nevada, and California. It was decided to focus on the southwest region because of similar weather patterns and familiarity with the region.

The sample set selected for this study was determined by the limited availability of an accessible list of water provider names. Ideally, one would draw a random subset of observations (water providers) from the total population to be contacted for purposes of providing water data. The "sample set" is assumed to possess a pattern of behavior similar to the total population so that random events cancel out one another and the resulting estimated parameters are "accurate" estimators of behavior for the real variables describing the parent population. In Colorado, no single entity exists (public or private) that accounts for all water serving utilities in the state. At the time the survey was being developed, it appeared that the AWWA had the most complete information on water provider contacts of any other organization. Fortunately for our project, the AWWA generously consented to provide their information, consisting of names of individuals and/or utilities involved in the providing of domestic water. Since the study was interested in securing information on more than just water production data (as the AWWA survey had concentrated on), it was decided to contact individuals who were coded as "water managers" in the AWWA database. Then, if other "specialists" were needed to provide specific information, the survey could be forwarded to the appropriate individual. In addition, by contacting just those individuals denoted as water managers, the problem of redundant mailings within the same utility was addressed (since many of the larger utilities had more than one contact listed depending upon the area of specialty). (It was also mentioned in the cover letter that if the addressee was inappropriate, to please pass the survey packet on to the appropriate individual(s).

The final sample set consisted of a selected subset of the AWWA membership mailing list for the aforementioned six southwestern states. For this thesis, only those surveys sent to municipalities and water providers located throughout Colorado were analyzed.

Conflicting objectives existed in attempting to design a survey that would encourage the reporting of accurate data in a form that could be readily utilized, that was flexible enough to allow for individual accounting styles, and that would not be a burden to the participating utility. In addition, because time and money were scarce resources, it was decided to maximize the collection effort by securing a data base that could be utilized to test additional hypotheses for future research.

The survey used by the AWWA in their data collection effort for their Annual Utility Reporting Data, 1980 and a questionnaire developed and utilized by Frerichs, Becker, and Easter (1987) in a similar research effort were used as models in the design and development of the survey used in this study. The survey packet was pretested by having it filled out by employees of water utilities in Northern Colorado. Resulting comments were reviewed, and appropriate suggestions were incorporated into the survey. (See Appendix I for a reproduction of the survey packet.)

The data requested from the contacted participants included monthly consumption data for two years, 1984 and 1985, broken down by the different user classes: single family residence, multifamily, commercial, industrial, public authority, irrigation, and other. In addition, information was requested on the number of households, population, the rate schedule, a description of a conservation program and number of years it had been in existence, and the number of nonmetered households being served. Since preliminary inquiries indicated that most water providers did not have information on such variables as income, temperature, and precipitation, outside sources were consulted for these variables. Data presented in the AWWA 1982 Annual Report indicated that for Colorado metered and nonmetered organizations were equally represented. Therefore, it was expected to receive a similar proportion with the survey. However, this was not the case. Out of eighty-eight contacts made, seventy-three were deemed appropriate water providing entities and capable of responding. Fifty-seven responded in one form or another. Thirty-eight responded with completed surveys from which thirty-three distinct reporting areas provided reliable annual data. This reflects a final return rate of 42%. By using data for two years, 1984 and 1985, a total of 66 observations of pooled data were used. Of these 66 observations, only 12 represent nonmetered areas (18%). Table 3.1 presents a breakdown of the results of the mailed surveys.

Table 3.1. Results of Surveys Mailed to Colorado Water Suppliers

Breakdown of Surveys	Number of Surveys
Total Number of Surveys Mailed	88
Total Number Deemed Applicable	73
Total Number of Responses	57
Total Number of Surveys Completed	38
Questionnaires with Annual Data	30
Questionnaires with Monthly Data	28
Questionnaires with Annual Data Only	7
Number of Questionnaires Promised But Not Received	11

Hypothesized Models and Preliminary Results

For this study, the dependent variable to be explained is the average monthly water consumption per household in gallons for single family homes. For metered customers, it is hypothesized that the demand for water will be affected by the following variables: average price, average yearly income, temperature, precipitation, frequency of billing, density per household, and the existence and duration of a conservation program. Since water is considered a normal good, water consumption is anticipated to vary directly with income. In addition, water consumption is hypothesized to increase proportionally to the number of persons per household, the longer the time between billing periods, and the average maximum summer temperature. Both average monthly maximum summer temperature and average total monthly precipitation are hypothesized to be reflected in the sprinkling demand. Precipitation is expected to influence water demand inversely as should the existence and duration of a water conservation program, and the average price per 1000 gallons of water consumed. The average price per

1000 gallons was calculated by dividing the average monthly (household) water bill by the average monthly (household) water consumption (in gallons).

For nonmetered customers, it is hypothesized that water demand will move in a positive direction with average yearly income, the number of persons per household, and the average monthly maximum summer temperature. In contrast, water demand should move inversely to the existence and duration of a water conservation program and the amount of precipitation received during the summer. Since nonmetered customers face a zero marginal price, so that the total water bill does not change regardless of how much water is consumed, they are not expected to respond to changes in average price. For income estimates, 1980 United States Census data were used.

National Weather Service records for temperature and precipitation data were consulted. Initially, we planned to use "evapo-transpiration rates" to represent climatic factors. However, data from the National Weather Service on evapotranspiration was lacking for many of the communities. This does not compromise the model as later reflection suggested that even though rates of evapo-transpiration would indicate when lawns <u>should</u> receive water, precipitation and temperature may, in fact, be the more accurate explanatory variable with regards to <u>people's perception</u> for sprinkling needs and the demand for water.

Descriptive Statistics

Simple descriptive statistics can serve as a useful analytical tool for comparison purposes between the different data sets. Table 3.2 lists the values for the average figures for the metered, nonmetered, and combined data sets for the dependent and independent variables. Table 3.3 lists the range of values for the metered and nonmetered data sets. Six variables, frequency in billing, monthly household consumption, average price per 1000 gallons, the marginal price per 1000 gallons, the average monthly water bill, and the duration a conservation program has been in existence are noticeably different in magnitude between the metered and nonmetered water users. Density also varies between the two groups but to a smaller degree, while temperature, precipitation, income, and the existence of a conservation program appear to be comparable.

Table 3.2. Descriptive Statistics For Colorado Residential
Water Use Data Sets For The Range Of Values (1984, 1985).

Variable	Metered	Nonmetered	Combined
Monthly household demand (gallons)	11,543	27,176	14,532
Average price ($/1000 gals.)	$2.25	$0.60	$1.95
Marginal price ($/1000 gals.)	$1.56	$0.00	$1.26
Average monthly water bill	$23.60	$16.31	$22.21
Billing frequency (months)	1.26	2.17	1.43
Density (persons/dwelling)	3.29	4.00	3.42
Conservation program (percentage)	0.52	0.50	0.515
Duration of conservation program (years)	4.60	2.60	4.36
Maximum daily temperature[a] (Fahrenheit)	83.72	82.83	83.55
Total monthly precipitation[a] (inches of rainfall)	1.76	1.75	1.76
Yearly household income ($)	$12,571	$13,840	$12,814
Average population (persons)	37,100	68,695	42,845

a\summer months

Table 3.3. Descriptive Statistics for Colorado Residential Water Use Data Sets for the Range of Values (1984-1985).

Variable	Metered	Nonmetered
Monthly household demand (gallons)	3,098 - 26,3962	15,182 - 45,982
Average price ($/1000 gals.)	$0.79 - $4.66	$0.20 - $1.22
Marginal price ($/1000 gals.)	$0.56 - $3.40	$0.00
Average monthly water bill ($)	$11.17 - $59.87	$8.00 - 22.28
Billing frequency (months)	1.0 - 3.0	1.0 - 3.0
Density (number of persons)	2.37 - 4.50	2.80 - 9.19
Duration of conservation program (years)	0 - 46	0 - 9
Maximum daily temperature[a] (Fahrenheit)	74.73 - 90.13	77.33 - 86.40
Total monthly precipitation[a] (inches of rainfall)	0.41 - 3.18	1.21 - 2.32
Yearly household income ($)	$9,421 - $17,573	$11,501 - $16,409
Average population (persons)	588 - 166,636	3,511 - 323,212

a\summer months

The differences highlighted in Tables 3.2 and 3.3 between metered and nonmetered water systems underscore the separate set of dynamics that operate under the different water systems. Nonmetered systems typically have access to relatively inexpensive water. Otherwise, mounting economic pressure would force the utility to switch to a metered system in order to have a more precise accounting of the water delivered. The absence of a reliable measure of water consumption makes it very difficult to keep accurate records. Therefore, when examining single family consumption data reported by a nonmetered system, it must be acknowledged that the estimates likely include system losses and/or water consumed by another user class that could not be separated out. The fact that the utility is willing to support this system reflects how inexpensive the water is relative to the cost to switching to a metered system.

This absence of real scarcity is likely conveyed to the consumer via low water bills, a low billing frequency, or a limited emphasis on water conservation. Of course, the existence of meters will not guarantee an accurate water accounting scheme or wise use of water, but without the capability to precisely monitor the distribution and consumption of water, it is very difficult for a utility to be efficient with its water. (A copy of the raw data is in Appendix II.)

Scattergrams

Graphical tools can also be useful in providing a visual depiction of an hypothesized relationship between variables. Three scattergrams are presented to discern if such a relationship between variables does exist. In spite of this author's agreement with Foster and Beattie concerning the preferability of average price, the proper price specification may in fact be an empirical question. Therefore, scattergrams were produced to determine if one of the two forms of price might be more closely correlated with the demand for water. Figure 3.1 depicts the relationship between the average price for water (dollars/1000 gallons) and the average monthly water consumption per household (gallons). Figure 3.2 depicts the relationship between the marginal price for water (dollars/1000 gallons) and the average monthly water consumption per household (gallons). In both Figure 3.1 and Figure 3.2, a downward sloping demand curve can be traced out. It is not obvious considering only the scattergrams that average price is significantly better at tracing out a demand curve than marginal price. Figure 3.3 depicts the relationship between average price and marginal price. A linear relationship between the two that is suggested by Figures 3.1 and 3.2 is visible in Figure 3.3. In this set of data, it appears that a high marginal price is associated with a high average price and visa versa. In other words, water users who have a high water bill <u>relative</u> to the amount of water they consume (and hence a high average price), also face a high marginal price.

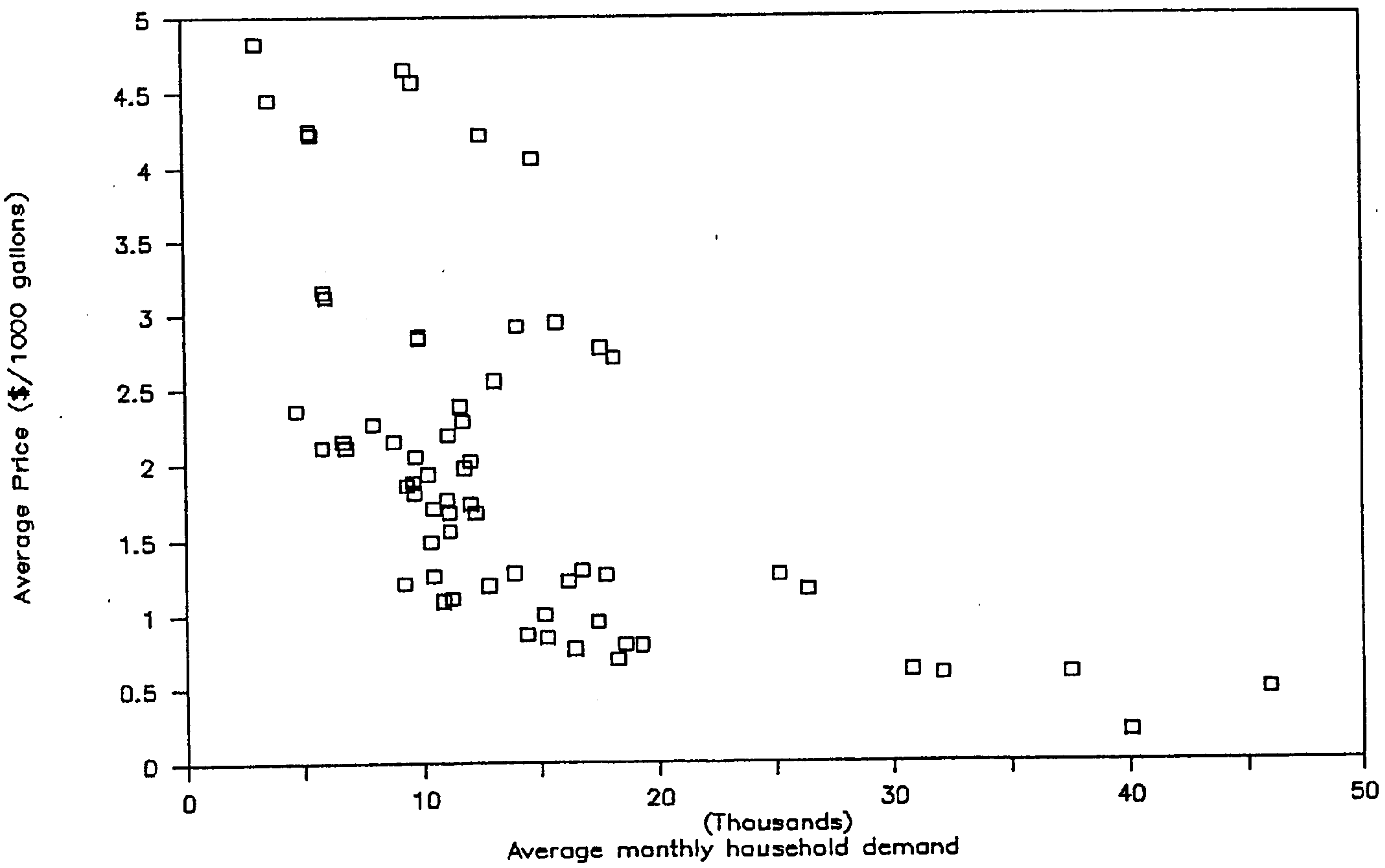

Figure 3.1 Plot of observations on average monthly household use of water. ($/1000 gal.)

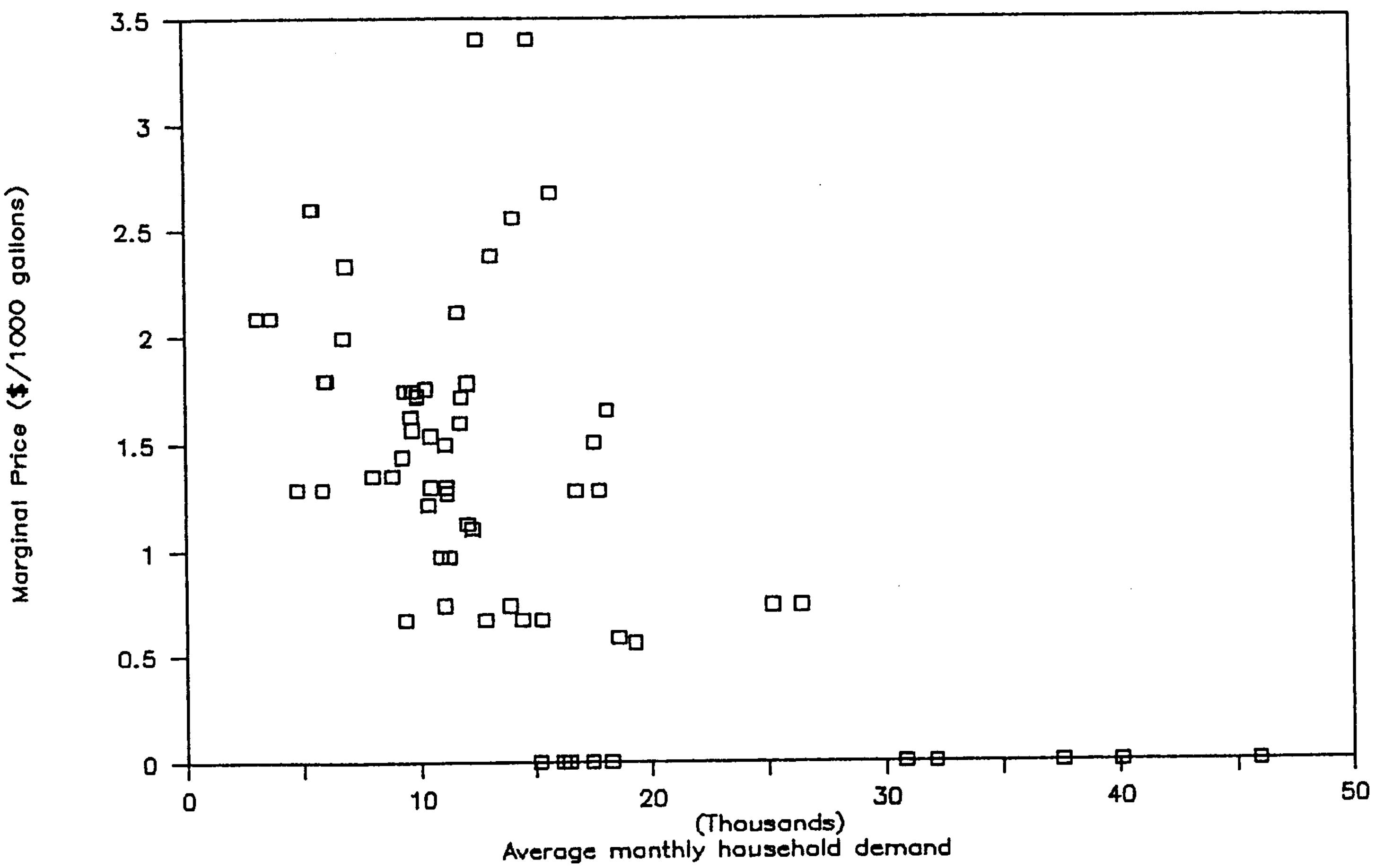

Figure 3.2 Plot of observations on marginal price and average monthly household use of water.

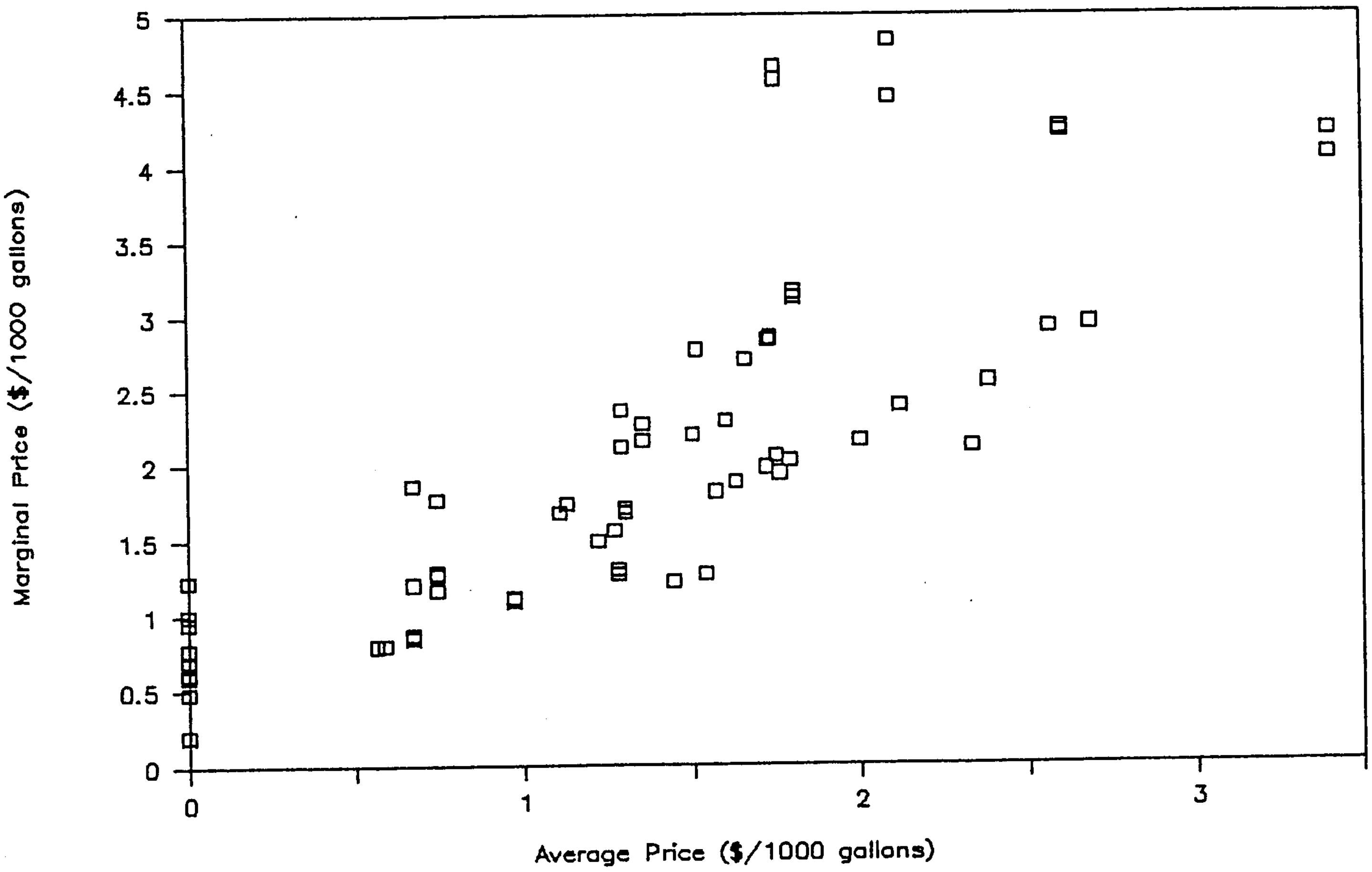

Figure 3.3. Plot of average price and marginal price of water.

CHAPTER IV

STATISTICAL ANALYSIS AND RESULTS

This chapter discusses the methodology and results of the statistical procedures and functional forms. Then the analytic process is described and results displayed.

Methodological Considerations

Regression Tests

The general purpose of this study is to identify and quantify those factors that influence residential demand for water in Colorado. A specific sub-objective is to determine if metered customers behave differently than nonmetered customers. In other words, are two different populations being observed with regards to water demand behavior. One approach to this problem is to test whether or not a structural change exists between the two groups. Such a procedure is outlined by Johnston (1984) and is accomplished by comparing the residual sums of squares of the "restricted" model to the residual sums of squares of the "unrestricted" model.

The terms "restricted" and "unrestricted" are relative depending upon what parameters are being tested. "Restricted" refers to constraints that are placed on the model. In this study, a restricted model forces both metered and nonmetered observations into at least one common parameter. This is the null hypothesis and can be stated as: H_0: $a_m + b_m X_m = a_n + b_{nm} X_{nm}$ (where "$_m$" denotes the metered data set, and "$_{nm}$" denotes the nonmetered data set.

The unrestricted model allows at least one of the parameters to vary between the metered and nonmetered sets. This is the alternative hypothesis and can be stated as: H_a: $a_m + b_m X_m <> a_{nm} + b_{nm} X_{nm}$. Theory and common sense are expected to provide direction as to what the restricted and unrestricted models will be.

The most unrestricted form of the model is comprised of two different regressions where both intercepts and slopes are allowed to vary between the two groups ("u" is the error term): $Y_m = c_m + b_mX_m + u$ (demand model for metered users) $Y_{nm} = c_{nm} + b_{nm}X_{nm} + u$ demand model for nonmetered users).

Or the two models can be combined into one regression still allowing the slopes and intercepts to vary: $Y = c_m + c_{nm} + b_mX_m + b_{nm}X_{nm} + u$.

Because more than one test is possible, Johnston (1984) has outlined a "hierarchy of models" that are used with this approach. These are presented in shorthand matrix form and are presented in sequential order starting with the most restricted model.

Model 1 formulates a common regression for both groups so there is no difference between water demand behavior. Their intercepts and rate of consumption are identical ("$_c$" denotes the combined data sets): $Y = c_o + b_cX_c + u$.

Model 2 formulates different intercepts but common slopes for the two populations. This is the situation that Hanke (1969) found in his study of Boulder, Colorado:

$$Y = c_m + c_{nm} + b_cX_c + u.$$

Model 3 formulates different intercepts and different slopes, thereby treating the two groups as two different populations that have different water demand functions:

$$Y = c_m + c_{nm} + b_mX_m + b_{nm}X_{nm} + u_m + u_{nm}.$$

The regression results for the different models are computed and the appropriate residuals are tested and compared with a modified F-statistic. The test for different slope coefficients compares the residuals for Model I to those of Model II, while the test for different slope coefficients compares Model II to Model III, and the test for different regressions compares Model

I with Model III. The formulas for the F-tests used to test the different null hypotheses are listed below the residual sum of squares (RSS) of the different models and are identified by their respective numbers with the appropriate degrees of freedom listed in parentheses:

(1) Test for different intercepts and common slope:

H_o: $Y = c_o + b_c X_c + u$ $\quad$ H_a: $Y = c_m + c_{nm} + b_c X_c + u$

$$F = \frac{RSS1 - RSS2}{RSS2/(N-K-1)} \sim F(1, N\text{-}K\text{-}1)$$

(2) Test for different slopes:

H_o: $Y = c_o + b_c X_c + u$ $\quad$ H_a: $Y = c_o + b_m X_m + b_{nm} X_{nm} + u$

$$F = \frac{(RSS2 - RSS3)/(K-1)}{RSS3/(N-2K)} \sim F(K\text{-}1, N\text{-}2K)$$

(3) Test for different regressions (different slopes and different intercepts):

H_o: $Y = c_o + b_c X_c + u$

H_a: $Y = c_m + c_{nm} + b_m X_m + b_{nm} X_{nm} + u_m + u_{nm}$.

$$F = \frac{(RSS1 - RSS3)/K}{RSS3/(N-2K)} \sim F(K, N\text{-}2K)$$

The K in the numerator is the difference in the degrees of freedom of the residual sums of squares obtained in going from the unrestricted model to the restricted model. In the denominator, K is the number of the variables in the specified model.[25] Because so little prior work has been done in testing for differences between metered and nonmetered behavior, three possible models are tested:

(1) One single regression representing a single population.

(2) Different intercepts but identical rates of consumption.

(3) Two different regressions reflecting two entirely different populations.

Because of differences in incremental charges between metered and nonmetered rate systems (positive vs. zero), one a priori expectation is that the rate of consumption (the slope) should be significantly different between the two groups. It is difficult to predict if the intercept terms should be identical or different because of the very low quantity of water necessary to satisfy basic human needs that the intercept term should (in theory) represent. In addition, because of the "junk term" role that the intercept term plays for the error term, it is usually difficult if not unwise to place much value on the intercept term.

Functional Form

For this study, it was decided to use a single equation, ordinary-least squares demand model. In light of the discussion presented in the literature review, the potential for simultaneity bias resulting from the employment of average price is considered small, and it is not clear that utilizing a more sophisticated statistical approach will yield a better model, especially without a more sophisticated understanding of how the different dynamics interact in their influence on the demand for water. However, even with the simpler ordinary-least squares, the proper functional form must still be chosen.

One criterion for choosing a particular functional form is what will be the resulting characteristic slope. A linear function will produce a constant slope but non-constant elasticities. A double-log function will produce a non-constant slope but constant elasticities. Partial-log equations can produce a variety of slopes and elasticities.[26] Economic theory is not definitive as to which functional form is to be preferred, because plausible explanations of consumer behavior can be presented for several different slopes and elasticities. Therefore, the choice of a functional form is considered to be as much of an empirical question as the choice of relevant variables. Consequently, linear, semi-log, partial-log in price, and log-log functions are considered. These functional forms have been employed in other water studies and have yielded satisfactory results.

Preliminary Analyses

Testing of Variables

Because the results of the scattergrams did not provide convincing support that average price would better explain the demand for water than marginal price, several price variables to represent price were tested in preliminary regressions. These included: average price; marginal price; average price and marginal price together; and marginal price with an income difference variable to pick up the income effect present in decreasing block rate schedules (Billings and Agthe, 1981).

Almost without exception, for this data set, the coefficient for average price taken by itself proved to be the most robust price variable and consistently outperformed the other price variables. The coefficient for marginal price by itself was also negative but less statistically significant in degree and was accompanied by less robust overall results. Since Figure 3.3 suggests a positive linear relationship between these two price variables, it is not surprising that both price variables appear to capture part of the price effect when used individually. However, when average price and marginal price were included together in the same regression to test for preferred consumer response, the coefficient for average price was always negative and significantly different from zero while that for marginal price was positive and usually statistically insignificant. The use of marginal price with an income effect variable produced inconclusive results similar to findings in other studies - the coefficient on marginal price was negative and significantly different from zero while that for the income effect variable was statistically insignificant. (For this data set, this result is not unexpected since only thirteen of sixty-six observations had a decreasing block rate schedule.) Based upon these preliminary results, it was decided to use average price by itself as the preferred price variable.

Initially, one other price-related variable was included in the preliminary models. It was speculated that the proportion of the fixed service charge to the total water bill might affect the demand for water. As mentioned earlier, the smaller the proportion of a flat rate service charge to the total incremental charge, the greater freedom people have in determining their total water bill. Inclusion of this variable produced inconclusive results. Several reasons exist that might explain why. One reason is that the effect of the fixed service charge to the total water bill is so small as to be negligible. Along the same lines, the water bill might be so small relative to total disposable income that <u>any</u> impact from a water bill is negligible.

Another variable hypothesized to affect the demand for water was the quantity of minimum gallonage allowed before application of the incremental charge. The smaller the quantity allowed, the greater the effect an incremental charge should have on water demanded. Results for this variable were indeterminate. As with the fixed service charge, it is possible that the proportion of minimum gallonage is so small relative to the total consumed and/or water is so inexpensive relative to income and spending power, that its effect on water demand is negligible. Both the fixed service charge and minimum gallonage were subsequently removed from the study due.

In addition, average yearly (household) income was initially included, but without exception, the coefficient of the income variable was found to have the wrong sign and could not consistently reject the null hypothesis. This statistical instability was present for metered, nonmetered, and combined data sets. Insufficient variation among the sample communities in the income data from the U.S. Census is one likely source of error.

One additional variable hypothesized to inversely affect water demand by both metered and nonmetered groups was the presence and duration of a conservation program. Moreover, with the absence of the economic incentive to conserve water that is provided by a positive marginal price, it was expected that nonmetered water users would be more strongly influenced by the presence and duration of a conservation program than metered users. However, preliminary results of the statistical test proved indeterminate. Both a dummy variable and a time variable (measuring the duration of the program) were utilized to try to capture any influence this variable might have but neither yielded any supportable results. The immense range in kinds and degree of quality of conservation programs in the study, no doubt, was too great to accurately measure with the variables available. This variable was also discarded from the study. Table 4.1 lists the dependent variable and the final independent variables for this study. All variables were used for both data sets. All units of measure are related to average annual consumption.

Table 4.1. Notation and Definition of Selected Model Variables.

Y = Average annual water consumption per household (gallons/household/year)

C = The intercept term for water users (gallons).

AP = The average price per 1000 gallons of water for water users ($/1000 gallons).

B = The billing frequency for water users (months between billing periods).

D = The density per water consuming household (number of persons per dwelling).

T = The average maximum summer temperature (June, July, and August) for water users (degrees Fahrenheit).

P = The average summer precipitation (June, July, and August) for water users (total inches per month).

U = The error term.

Preliminary Testing of Alternative Models

Initial analysis of the models yielded relatively weak results, especially for the nonmetered data set. This was not unexpected given earlier concerns associated with the small sample set (thirty-three total observations for each year with six nonmetered observations for each year). Since individual models for each separate year and for each metering system seemed lacking, it was decided to run a series of regressions. The idea being that each succeeding series would expand the sample set either by increasing the time period (from one year to two years) and/or, by expanding the data set (by combining metered and nonmetered data). It was hoped that a trend of increasing robustness in the results would emerge that would provide adequate support for the hypothesized models describing metered and nonmetered water demand and any difference between them. This methodology allowed for statistical analysis to be done in spite of the very low number of nonmetered observation points which severely curtailed the ability to compare separately run regressions.

The first level of regressions utilized metered data from the first year only. The second level utilized metered data from the second year only. The third level was expanded to combine metered data for both years. Next, metered and nonmetered data were combined together for both years. And finally, metered and nonmetered data were combined for both years but separated with the use of dummy variables. Four functional forms (used in other water demand studies) were employed: linear, semi-log, partial-log in the price variable, and log-log. For the first three stages of regressions, the results are not strikingly different, although some distinguishable patterns do emerge. In general, for metered (linear), it appears that the adjusted R^2's and F-statistic vary between models as a function of what weather variables are included. When temperature was included as the weather variable, the second year was a little stronger in explanatory power ($R^2 = .54$ vs. $R^2 = .49$). When precipitation was the only weather variable, the second year showed slightly stronger results for the adjusted R^2 ($R^2 = .54$ vs. $R^2 = .488$).

The coefficients for the two different years were comparable overall. AP_M was always negative and statistically significant, while the constant term fluctuated as did the weather variables. Usually the weather variables demonstrated the expected sign but varied in the degree of statistical significance. Billing and density exhibited some differences between the two years. B_M was always positive and significantly different from zero in the first year. For the second year, B_M was still positive but not statistically significant. D_M was always positive and significantly different from zero in the second year, but positive and statistically insignificant in the first year.

When the two years were combined, the results improved as the degree of significance of the coefficients stabilized in consistency and sign throughout the regressions. The improvement was not dramatic but was noticeable. Along with average price, the coefficients for both density and billing stabilized and were now consistently significantly different from zero and of the hypothesized sign. For the two years combined (metered only), the F-statistic, without exception, doubled in value, while the adjusted R^2 either increased slightly (approximately five points) over that for either year or remained comparable.

The predicted values of the coefficients as given by the models for the first three levels of regressions where only metered data was used, were consistent with data averages. (For the log-log function, however, those models often predicted unrealistic values for some of the variables - temperature in particular - despite the apparent "normalness" of the final predicted value for water consumption.) Next, the nonmetered data points were included for both years but were not differentiated by dummy variables. It is difficult to predict a priori if combining metered and nonmetered data observation points will yield better or worse results. For some variables (e.g. temperature, precipitation, and density), it is likely that metered and nonmetered will behave similarly in kind but different in degree. Other variables, (e.g. price and billing), are likely to exhibit opposite effects on water demand. The relative strength of the different variables will determine whether there will be more or less explanatory power by the models.

For the combined data sets of metered and nonmetered, there is a slight reduction in goodness of fit in those models in a linear functional form: many of t-statistics for the coefficients declined slightly as did the value for the F-statistic and the adjusted R^2. For all nonlinear functions, the values for the t-statistics varied slightly -some decreased while some increased with no notable exceptions except for density and the partial-log functions. In this situation, density, which had been consistently positive and statistically significant for metered only (both years combined), now became statistically insignificant. For all three nonlinear functions, the F-statistic doubled in value from the regression before while the adjusted R^2 increased by five to thirteen points.

The last stage of regressions combined metered and nonmetered data points for both years but separated them in the regression with dummy variables. This is the stage that allows for testing between metered and nonmetered water demand behavior. This last series of regressions also differentiated between a common intercept term and different intercept terms for metered and nonmetered respectively. (Initially, the question was raised as to whether both the level and rate of water demand would differ between water users or if the rate alone would differ between the two populations. It was decided to disregard a model with a common intercept term due to inconsistencies in data and the resulting unknown errors.)

In general, by combining and separating out metered and nonmetered observations, the results of this last series do consolidate and strengthen earlier results. The adjusted R^2's increased noticeably (between ten to twenty points) so that all models were explaining 70% to 80%+ of the variation in water demand. The F-statistics either increased or remained comparable, and the Durbin-Watson test statistics were either able to reject the null hypothesis of serial correlation or were indeterminate, and the variable coefficients solidified the repeated patterns of demand behavior that were suggested by earlier regressions.

For metered water users, regardless of functional form or model, the coefficient for average price was always negative and consistently significantly different from zero at the 0.5% level, while those for billing and density was always positive and significantly different from zero at 10% and 5% (or greater) respectively. The coefficient for precipitation was always negative and significantly different from zero for six out of the eight models where precipitation was included, while the coefficient for temperature was always positive and significantly different from zero for six out of the eight models where temperature was included. The constant term was usually positive and significantly different from zero in the log models, except for the log-log models where it was always negative and statistically insignificant. For the linear models, it was always positive but usually statistically insignificant.

For nonmetered water users, the results do not so much identify what influences their demand for water, but rather, identifies what does not influence their demand for water as reflected by the generally weak coefficients. However, some repeatable patterns do emerge. Except for one model, the constant term is always positive and significantly different from zero. The coefficient for average price is always negative and significantly different from zero (not as expected), while that for billing is always statistically insignificant. The coefficient for density is never positive and significantly different from zero as hypothesized, rather it is usually negative and oftentimes statistically significant. The coefficient for precipitation is always negative but only statistically significant in three out eight models, while the coefficient for temperature varies in sign but is never significantly different from zero when positive.

For overall results, the linear models outperform the log forms with regards to adjusted R^2's, Durbin-Watson value, and the F-statistics. For the models in linear form, the adjusted

R^2's ranged from .80 to .83, the Durbin-Watson values are 2.02 to 2.07 (serial correlation is absent), and the F-statistic ranges from 29.24 to 35.13 (the coefficients are significantly different from 0; $X_1 <> X_2 <> X_3 <> 0$.) Contrast this to any of the log forms where the adjusted R^2's = .685 to .71, the Durbin-Watson values range from 1.30 to 1.65 (serial correlation is indeterminate), and the values for F-statistics range from 15.16 to 19.06 (the coefficients are significantly different from zero).

The predicted values for monthly household water demand were satisfactory for the linear and semi-log models but not so for the partial-log and double-log models. The partial-log models predicted average monthly household water demand to be under 1000 gallons for both metered and nonmetered water users, while the double-log models produced even more unrealistic figures. For the double log models, the predicted values for metered monthly demand were unbelievably low (e.g. 0.0048993 gallons), while the predicted values for nonmetered demand were unrealistically high (e.g. 172,123 gallons).

Final Models

Modified F-tests as outlined earlier in this Chapter are used to determine if metered and nonmetered water users behave differently enough to be statistically different populations. Three models in the linear form and three models in the semi-log form are able to reject the null hypothesis that $Y_M - Y_{NM} = 0$, and only one partial-log model and no double-log models are statistically significant in rejecting the null hypothesis that metered and nonmetered water users behave identically. From these different regressions, four models emerge that best support the original hypotheses proposed by this study as well as exhibit the most robust results. These models have been chosen for their consistency and degree of statistical significance of hypothesized variables, overall robustness, F-test significance (testing for different populations), and predictive capability. One linear and three semi-log models are presented in Table 4.2.

Table 4.2. Estimated Water Demand Models.

Model	**Equation**
L-1 Linear	$Y = c_M + c_{NM} + a_1AP_M + a_2AP_{NM} + a_3B_M + a_4B_{NM}$ $+ a_5D_M + a_6D_{NM} + a_9P_M + a_{10}P_{NM} + U_M + U_{NM}$
SL-1 Semi-Log	$\ln Y = c_M + c_{NM} + a_1AP_M + a_2AP_{NM} + a_3B_M + a_4B_{NM}$ $+ a_5D_M + a_6D_{NM} + a_9P_M + a_{10}P_{NM} + U_M + U_{NM}$
SL-2 Semi-Log	$\ln Y = c_M + c_{NM} + a_1AP_M + a_2AP_{NM} + a_3B_M + a_4B_{NM}$ $+ a_5D_M + a_6D_{NM} + a_7T_M + a_8T_{NM} + a_9P_M$ $+ a_{10}P_{NM} + U_M + U_{NM}$
SL-3 Semi-Log	$\ln Y = c_M + c_{NM} + a_1AP_M + a_2AP_{NM} + a_3B_M + a_4B_{NM}$ $+ a_5D_M + a_6D_{NM} + a_7T_M + a_8T_{NM} + U_M + U_{NM}$

The level of significance for testing for different populations (modified F-test); the coefficients and their t-statistics and level of significance; the adjusted R^2; the Durbin-Watson value (for serial correlation); and the F-statistic for individual coefficients are listed in Table 4.3.

The level of significance for a one tailed test as denoted by the T-statistic is indicated by the number of asterisks in superscript form to the right of the parentheses: no asterisk = is not significant, "*" = 10 % level of significance, "**" = 5% - 2.5% level of significance, and "***" = 1% level of significance. Table 4.3 presents those regression results.

The selected models explain between 71% to 83% variation in the demand for water. In the estimated models, serial correlation is either absent (linear model) or indeterminate (all semi-log models). For all four models, the F-statistic is significantly different from zero at the 1% level of significance level. In addition, all four models reject the null hypothesis that $Y_M - Y_{NM} = 0$ at the 1% level of significance.

Discussion of Results for Individual Variables

Price

For metered water users, average price is consistently negative and statistically significant (1% level of significance). The (average) price elasticities of demand are inelastic and range from -0.31 to -0.33, which are typical of price elasticities found in other studies. Unexpectedly, the models show nonmetered water users to be responsive to changes in average price. Unexpectedly, the models show nonmetered water users to be responsive to changes in average price. All coefficients were negative and significantly different from zero (at the 1% significance level). The "price elasticities" produced were less inelastic than those for metered (-0.648 to -0.756).

Billing

The impact of the frequency of billing was also very consistent throughout the models. B_M was significantly different from zero (1% - 5% level of significance). However, for metered water users, it was observed that whenever density and billing were included together, the impact and significance of the coefficients for both variables was consistently diminished in comparison to when one was excluded. A positive correlation of .65 was found to exist between the two variables. Since no obvious reason to explain their correlation could be identified, the variables were both included in the model. As expected, the frequency of billing had no impact on nonmetered water users.

Table 4.3 Regression Coefficients from the Selected Models.[a]

Variables	**L-1**	**SL-1**	**SL-2**	**SL-3**
C_M	8001 (2.38)***	9.11 (33.80)***	7.20 (6.40)***	6.61 (6.24)***
C_{NM}	67368 (9.40)***	11.53 (20.06)***	12.70 (4.14)***	10.98 (4.05)***
AP_M	-1731 (-3.52)***	-0.20 (-5.16)***	-0.19 (-4.76)***	-0.18 (-4.53)***
AP_{NM}	-32627 (-8.07)***	-1.23 (-3.79)***	-1.26 (-3.83)***	-1.22 (-3.70)***
B_M	3517 (3.07)***	0.19 (2.03)**	0.178 (1.95)**	0.18 (1.92)**
B_{NM}	676 (0.46)	0.05 (0.41)	0.035 (0.29)	0.035 (0.29)
D_M	1664 (1.59)*	0.186 (2.21)**	0.166 (2.01)**	0.167 (1.98)**
D_{NM}	-1936 (-2.02)**	-0.07 (-0.92)	-0.077 (-0.99)	-0.05 (-0.64)
P_M	-446 (-1.66)*	-0.044 (-1.93)**	-0.033 (-1.43)*	-
P_{NM}	-2069 (-2.57)***	-0.69 (-1.07)	-0.079 (-1.15)	
T_M			0.023 (1.74)**	0.027 (2.16)**
T_{NM}			-.013 (-0.387)	0.001 (0.047)
Adj.R^2	.83	.71	.71	.71
D-W	2.07	1.46	1.53	1.65
F-stat.	35.13 (2.70)***	18.34 (2.70)***	15.62 (2.66)***	18.27 (2.70)***
F-test	18.27 (3.51)***	4.38 (3.51)***	3.53 (3.29)***	4.33 (3.51)***
N =	55	55	53	55

[a] See table for the list of variables. Student's "t" statistics are shown in parentheses.

Density

The coefficient for density (per household) was, as expected, positive and significantly different from zero (2.5% - 10% level of significance) for metered households. Surprisingly, this same result was not found for nonmetered households. In fact, D_{NM} was consistently negative for nonmetered households, and in model L-1, it was significantly different from zero at the 2.5% level of significance.

Weather

For metered water users, the coefficients for the weather variables were consistently significantly different from zero and of the right sign for both precipitation (2.5% - 10% level of significance) and temperature (2.5% - 10% level of significance). For nonmetered water users, in only one model (L-1) was a coefficient for a weather variable (precipitation) significantly different from zero (at the 99% level) and of the hypothesized sign.

Predictive Capability of the Models

Predicted values for some of the variables for metered demand are presented in this section. Because the results for nonmetered demand are so weak, their predicted values will not be presented in table or graph form. To do so, would infer a degree of conclusiveness that is not supported by the results. While the predicted values for nonmetered water demand appear to be within a normal range (3% to 13% above the nonmetered data set average), the lack of explanatory power for nonmetered demand, weak coefficients, and unrealistic predicted values for some of the independent variables, offer little support for the nonmetered part of the models's predictive capability. Table 4.4 lists the average monthly water demand for metered residents as predicted by the selected models along with the actual average monthly consumption for the data sets. In general, predictions for metered consumption are lower than the average (0% - 9%).

Table 4.4. Predicted Monthly Water Demand for Metered Users in Gallons per Month.

Model	Metered (Gallons)
L-1	11550
SL-1	10683
L-2	10835
SL-3	10520
Average Value of Predictions	11543

Demand curves describing the hypothesized relationship between price and consumption are presented for the four models in Figure 4.1. The estimated models are used to calculate the demand curves depicting a change in water consumption given a change in the average price of water. Similarity in rate of demand appears to be a consistent pattern for the plotted demand functions as the four estimated models plot out fairly similar demand curves. The semi-log model (SL-1) demonstrates the greatest variation, while the other semi-log models plot an almost identical graph except for the y-intercept. This indicates a similar rate of consumption between the different models, but slightly different levels of consumption possibly as a function of what weather variables are included in the respective regressions.

The billing frequency and its predicted impact on water demand is presented in Table 4.5. The number listed under "billing indicates the number of months between billing mailings.

Table 4.5. Frequency in Billing and Predicted Metered Monthly Household Water Demand.

Billing	Models			
Months	L-1	SL-1	SL2	SL-3
1.00	10635	9997	10425	9730
1.26	11550	10683	10835	10520
2.00	19079	12052	12444	12469
3.00	22595	14530	15413	14898

Though this study was limited to using annual data, one would expect the frequency of billing to exert a greater impact during the summer when the demand for sprinkling is highest and the consumer faces a larger water bill than during the other seasons when the sprinkling demand is low. Realistically, the frequency of billing cannot be any smaller than one month between billings given the present billing procedures adopted by most water utilities.

Table 4.6 shows the positive relationship between density and metered water demand as estimated by the models.

Table 4.6. Impact of Density on Metered Water Demand.

Density	**Models**			
(# Persons)	L-1	SL-1	SL-2	SL-3
2.37	10019	8932	9350	8785
2.50	10235	9150	9533	8978
3.00	11067	10037	10394	9760
3.29	11550	10683	10835	10520
3.50	11899	11009	11305	10609
4.00	12731	12076	12296	11533

The numbers listed in Table 4.6 depict the number of persons per household (3.29 is the average) and the corresponding predicted monthly (household) demand for water by household in gallons. As expected, as density increases, the demand for metered water increases. (This finding provides support for the idea that the proportion of domestic water demand is high enough relative to total water demand that it is not overshadowed by the outdoor demand which might be the situation with density and nonmetered water demand).

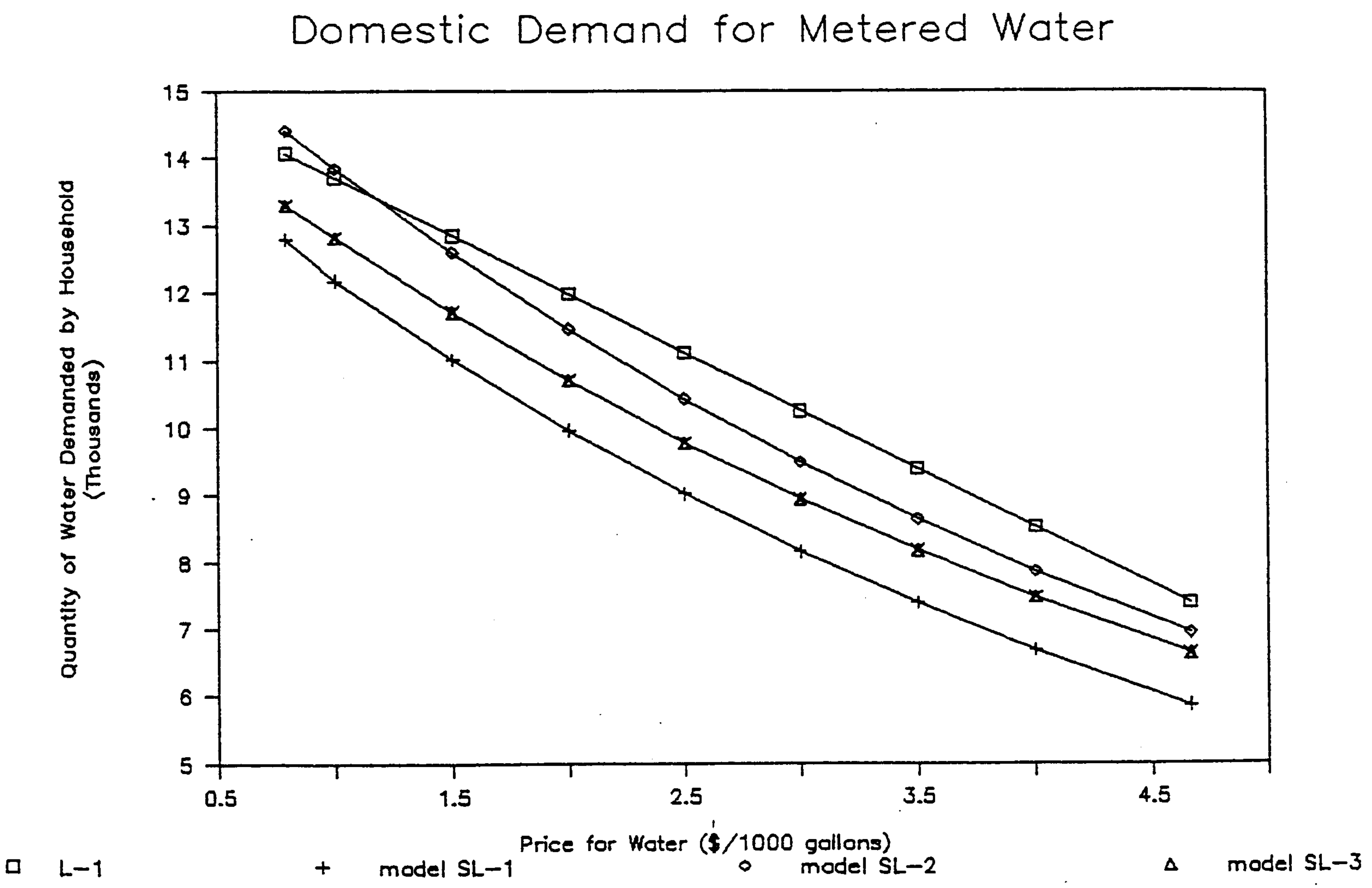

Figure 4.1 Demand curves for metered water users as predicted by the models L-1, SL-1, SL-2, and SL-3.

Price Elasticities

Price Elasticities for metered water users derived from the models at the mean quantities are presented in Table 4.7. The figures for metered Colorado utilities are consistent between models and range from -0.33 to -0.46.

Table 4.7. Price Elasticities Derived from the Estimated Models.

Model	**Metered**
L-1	- 0.337
SL-1	- 0.457
SL-2	- 0.425
SL-3	- 0.405
Average	- 0.406

"Price elasticities" were also derived for nonmetered water users. The estimates range between -0.72 to -0.76. There appears to be a strong negative correlation between average charges and average consumption, although this relationship cannot be properly termed a price elasticity of water demand. It might be conjectured that either consumers respond inversely to average cost (even if marginal charges are zero) or that the scarcity of water is communicated to users by means other than price.

For comparison purposes, Table 4.8 lists price elasticities derived from other studies. Table 4.8 provides a context against which the results of this study can be compared to results derived from other studies. These other studies used average price and cross-sectional data. This combination most closely approximates this study's use of pooled data and average price. Very few studies have used pooled data so direct comparisons are difficult to make. As can be seen, the average price elasticities derived from this study are comparable with those listed in

Table 4.8. The range in the price elasticity values presented (in Table 4.8) can be attributed to such factors as: different functional forms, different relevant variables (e.g. cultural and geographical parameters; Foster and Beattie, 1979), and varied degrees of the quality of data employed.

Table 4.8 Price Elasticities from Selected Water Demand Studies.[26]

Author(s)	Price elasticity
Ware and North (1967)	- 0.67, - 0.61
Turnovsky (1960)	- 0.28, - 0.25
Primeaux and Holland (1973)	- 0.26, - 0.37, - 0.45
Grunewald et al. (1979)	- 0.92
Foster and Beattie (1979)	- 0.47, - 0.52, - 0.65 - 0.30, - 0.33, - 0.38 - 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
Average price elasticity	- 0.46

The studies cited in Table 4.8 relied almost exclusively on metered data and/or nonmetered data that was included in the data set but not separated out.

CHAPTER V

SUMMARY AND CONCLUSIONS

Overview

This study was undertaken to identify factors affecting residential water demand in Colorado, and particularly, what differences, if any, exist between metered and nonmetered water users and their respective demands for water. Data used in preliminary analysis published by the American Water Works Association in their 1982 production report[27] indicated that half of reporting membership utilities for Colorado were nonmetered and further, that nonmetered customers, on the average, used more water per household. If that information was reflective of all of the water utilities in Colorado, significant savings in water might made in switching to metered systems.

A clearer understanding of the differences in water demand behavior between metered and nonmetered water users was needed. A literature search of the subject yielded surprisingly little except for the early report by Howe and Lineaweaver (1967). And, despite a significant difference of the mean being obtained with the AWWA data, our preliminary statistical analysis proved unable to establish additional reliable relationships. Since all further leads for securing reliable consumption figures for water demand for any of the southwestern states proved futile, it was decided to initiate a mail survey for the purposes of securing reliable data from water utilities. It was assumed that the AWWA production report to be reflective of the ratio of metered to nonmetered utilities, so that this approach appeared to be a reasonable way to secure needed data for both groups of water users.

An explanation of why there might be a problem in obtaining nonmetered water consumption data appeared with the results of the mail survey. Between 1982 and when the survey was sent in 1986, the percentage of nonmetered utilities had either declined in numbers, or no longer had membership with the AWWA based upon the responses that were received. Several of the utilities that were contacted indicated they had recently switched to a metered system or were in the process of switching. Many of these were unable to provide any nonmetered data for the requested years.

In addition, many of those utilities that were still nonmetered were unable to complete the survey because the requested information did not exist. (This situation was also applicable to some metered utilities, but more often other reasons were supplied as to why the survey could not be completed such as limitations on staff and/or time.)

In general, the results from the survey indicated that good, reliable data could be difficult to obtain. One likely explanation for this situation is that it is not uncommon for utilities (metered and nonmetered) to be "production" oriented in their approach rather than "consumption" oriented. Their focus (and subsequent available data) is oftentimes directed to where the water comes from rather than where it goes. A not uncommon comment that was received was, ". . . we have no such breakdown for the information you are requesting."[28] In addition, evaluation of the returned questionnaires produced the realization that reliable data for some variables were almost inherently elusive. Numbers for population figures and conservation programs proved especially spotty. It also became apparent that an inevitable amount of bias was present in the data because of the "casual" accounting practices used by many water utilities with regards to consumption figures for different user groups. It is not uncommon for utilities to combine several water user classes into one or two inclusive classes. This situation seemed especially chronic for nonmetered data because most nonmetered systems are unable to accurately measure water consumption by user class. This appears to be an inevitable problem with the data and no statistical technique can compensate for it since quantification of the error is an unknown. For this study, several responses were discarded due to poor quality and/or insufficient data despite the need for an adequate sample size. Based upon the survey responses, it appears that despite cries of pending water shortages in Colorado, water is oftentimes produced, sold, and measured as if it were not particularly scarce.

The data collecting portion of the survey did not yield the number of responses originally expected, especially regarding nonmetered data. However, the remaining data that was used for the study is considered reliable in spite of the small sample size. After much discussion, it was decided that a statistical technique was available to partially compensate for some of the deficiencies of the data, and make possible the pursuance of the original hypothesis.

The Results

A series of regressions were utilized as a mechanism to try to establish a consistent pattern of behavior for water demand. And in fact, consolidation of the results did emerge from this sequence of regressions. Patterns of behavior that were suggested by earlier regressions were statistically supported. The results of any one model were too weak to offer any substantial support for the original hypotheses. But taken together, the trend of results that was established provided statistical support for metered water demand, and provided circumstantial support for non-metered water demand and differences in behavior between the two consuming groups.

It appears from the results presented in Chapter IV, that the increase in statistical validation is largely directed towards the metered data set. Several fluctuations in the metered data set in the first two stages was smoothed out in the later stages as the sample set was expanded. In general, statistical measures such as the adjusted R^2 and the F-statistic improved as did the reliability of certain variable coefficients. D_M (density for metered users) which was usually significantly different from zero for the first year only, and B_M (billing for metered users), which was not significantly different from zero for the second year stabilized at a consistent level of significance in the later regressions. (See Table 4.1 for variable definitions). The same can be said for the weather variables, T_M and P_M (temperature and precipitation for metered users, respectively).

In contrast, satisfactory results for the nonmetered samples did not materialize. And although some variables were consistent (AP_{NM} was always negative and significantly different from zero, B_{NM} was never significantly different from zero), most coefficients could not refute the null hypothesis ($a_ix_i = 0$). Due to the "nonexplanatory" power of the model(s) to explain nonmetered water demand, this study can offer only circumstantial evidence for nonmetered water demand. It is difficult to say if the variables included in this study do not influence nonmetered demand and/or if the hypothesized relationships were not sufficiently developed because of the low number of nonmetered observations, and/or if the quality of the nonmetered data set was insufficient.

Limitations of the study to be explained include why some variables, initially hypothesized to influence the demand for water, were excluded from the study, and why certain variables for nonmetered demand, in general, did not perform as expected. For both metered and nonmetered demand, the presence of a conservation program was expected to negatively influence the demand for water. Income, or some proxy for income, is expected to positively influence water demand. However, it was not uncommon for the income variable(s) to exhibit poor results. In earlier studies, this problem has been attributed to poor data, a lack of variation in the cross-sectional sample data, correlation among proxy variables, and/or a very small water expenditure to total income ratio. In this study, all of the above may have contributed to the lack of statistical significance demonstrated by the income variable.

The conservation program variable also proved indeterminate. The absence of any clear pattern of behavior for this variable is likely due to the immense amount of variation that exists in conservation programs between water systems and the difficulty in adequately quantifying that variation. There are so many different dimensions to a conservation program: type of program(s) employed, degree of implementation, perceived need and burden of incidence, degree of commitment by the utility, etc. Even with accurate and reliable data, it would be very difficult to quantify this variable.

Specifically regarding nonmetered water demand, several variables in the study exhibited unexpected results. For example, density was expected to positively influence the demand for nonmetered water. Surprisingly, D_{NM} was usually negative in the non-metered sample, and not often significantly different from zero. It is not clear why water demand would decline as the number of persons per household increases for nonmetered households. Assuming that density and nonmetered water demand are positively related, one possible explanation would question the reliability of the population figures provided by the utilities. (And in fact, several water managers made cautionary remarks concerning the reliability of the population figures being provided.) This situation in combination with the small number of nonmetered data points may be responsible for the inability to support the a priori hypothesis.

Of course, it is possible that density and nonmetered demand are inversely related despite the initial hypothesis. This situation could exist if the difference between metered and nonmetered users is primarily concentrated in their respective outdoor watering demands, and if domestic indoor water demand for nonmetered users is small enough relative to their outdoor water demand. Then, an increase in density on total water demand for nonmetered users would be overshadowed by the dominance of the outdoor demand. The use of monthly data versus average annual and the separation of indoor from outdoor demand might better clarify this relationship.

And still another explanation is that nonmetered systems might have a higher percentage of large families, and that larger families are less able to afford large yards.
A reduced sprinkling demand would result in a lower total consumption. For this study, five of the six nonmetered communities have strong agricultural ties where large families are common.

The effect of weather variables on nonmetered demand also proved elusive. The initial hypothesis postulated that nonmetered users would be less sensitive to changes in temperature and precipitation (and the subsequent impact it would have on outdoor demand) than metered users. This hypothesis was supported by the results only in the sense that the results failed to support nonmetered water demand relative to metered demand. Therefore, it is inappropriate to conclude from these results that nonmetered residents are less sensitive to changes in temperature and precipitation than metered residents. However, it should be noted that whenever the two populations were treated as one for temperature and precipitation, the statistics for the coefficients, T_C and P_C (temperature and precipitation for metered and nonmetered combined, respectively), were not weakened and in some cases even strengthened.

In general, the weather variables demonstrated the greatest degree of fluctuation in the regressions. This is not surprising given the variable nature of both the weather variables and the reporting of data. The actual weather phenomenon, perception, and recording of weather can be highly dependent upon local conditions and subject to human perception and interpretation. It is not uncommon for a single weather station to be the only point of weather data collection for several miles. Therefore, the events and quantities recorded by a weather station may differ significantly from the weather encountered by nearby areas. One might reasonably assume that errors will average out in the long run, but for a short term study with a small sample such as this, discrepancies between recorded data and information utilized by the water user may be too great to be compensated for by the assumptions of randomness. Both temperature and precipitation can demonstrate variation within short distances. However, precipitation can vary immensely in quantities and distribution patterns especially with regards to its impact on the demand for water (sprinkling demand). Therefore, discrepancies in precipitation data between the recording station and nearby communities might be expressed with less dependable results. In this study, P_M (precipitation for metered users) appeared to be the more consistently significant (different from zero), though T_M (temperature for metered users) appeared to exert greater impact on water demand when it was statistically significant.

An additional problem for the nonmetered water demand models is reflected in the values assigned to the intercept term(s). The models oftentimes assigned a high proportion of total water demand to the intercept term. (This phenomenon was especially acute with the log-log function and can be interpreted as additional evidence illustrating the difficulties associated in trying to model for nonmetered water demand in addition to a poorly defined role for the intercept or constant term.) For nonmetered users, the value(s) for the intercept term(s) predicted by the models also was proportionally higher than that predicted for metered water users. In all of the models, the intercept term for nonmetered demand was greater than required to cover basic water needs.

The consistency in sign and significance of the coefficient for average price for nonmetered demand presents the result most difficult to explain. As was postulated earlier, the coefficient for AP_{NM} was expected to be statistically equal to zero. The most obvious explanation for why this is not so, is that the results are spurious. And certainly, one does not have to look far for a reason given the small sample set for nonmetered data, and, a priori, that nonmetered customers should not respond to an incremental "price" since one does not exist. However, for argument's sake, let us assume that the results are not spurious and in fact, a negative relationship does exist between average price and nonmetered water demand. Is there an explanation that can support this finding?

The crux of why this finding might be spurious is based upon the assumption that people respond to changes in marginal price. Since nonmetered water users have a zero marginal price, they should not be affected by any incremental price as dictated by economic theory. They pay a set rate regardless of how much water they consume. However, earlier in the study the question of people's "perception" concerning the price of water was raised since most other consumer goods are bought on an incremental (per unit) basis. Therefore, when a consumer is in a store musing over prospective purchases, a linear way of thinking might be a likely tool of analysis. What is the best buy that will provide the lowest average price for the unit bought? And in fact, the resulting "linear" function may be such a common response to price comparison buying, that it may be an unconscious reaction even when it is not deemed appropriate (theoretically speaking), such as when flat-rate pricing is present. Is it possible that consumers have been so conditioned to using price as a mechanism to regulate the consumption and use of a resource, that if the real marginal cost is not obvious, one will be created? Hence, the nonmetered water users in this study had developed a mental incremental "price" for water in spite of standard theoretical expectations. Their perception of the cost of water was likely less defined or maybe not even consciously recognized, but it existed and decisions regarding the use of water were made based upon that perception.

Of course, if nonmetered water users do perceive a positive marginal price for water, then one would expect the frequency of billing also to affect the nonmetered demand for water. However, the results consistently indicated that billing did not affect the nonmetered demand for water. Why should nonmetered water users appear to be so responsive to price but not to billing frequency? The data for this study shows that only one nonmetered utility mailed their billing on a monthly basis. The majority were mailed bimonthly with a few mailing water bills every three months (average = 2.17 months). Such a lack of variation in combination with the small sample set might explain why the regressions for nonmetered water users failed to reflect a response to billing frequency yet appeared to respond to changes in average price.

Summary

In summary, this study attempted to quantify differences in water demand behavior between metered and nonmetered water users. Why such a dearth of analysis on nonmetered water demand existed despite a predominance of nonmetered systems until recently became apparent as the study evolved: nonmetered water data is inherently elusive. It is very difficult to say, categorically, that nonmetered systems fit into one pigeon hole of description and metered systems fit into another. Individual utilities in both systems presented evidence of a rather casual approach to accounting for water and a general lack of intense concern as to where the water was going - either to consumption and/or system losses. However, as the study developed, overall patterns of behavior emerged that separated and identified different modes of behavior between the two groups. For example:

(1) Of the nonmetered utilities contacted, the majority could not provide the requested data.

(2) The average charge for water produced by nonmetered systems was noticeably lower ($0.60/1000 gallons) than the price for metered water ($2.25/1000 gallons).

(3) The average monthly household demand was higher for nonmetered (27,176 gallons) than metered (11,543 gallons).

Since the nonmetered data is more likely to contain system losses (and/or water demand for other user classes), it is not unlikely that the consumption figures are inflated. Subsequently, when calculating the average price of water, that price will be deflated downwards due to the inflated consumption figure. A more accurate comparison may be the average monthly bill of the two data sets, nonmetered ($16.31) and metered ($23.60).

In light of these observations and despite their resistance to quantification, common sense suggests that nonmetered systems will probably utilize more water than metered systems, ceteris paribus. It is difficult to defend casual management of a resource if it is truly perceived to be scarce. Therefore, it is likely that nonmetered systems reflect a secure and plentiful water source relative to expected demand. In such cases, a tight accounting system is not critical because of a perceived low risk of exceeding consumption limits and costs are not perceived as excessive by the consumer.

Given this elusive "background" information, it is understandable why some of the results of this study were weak and inconclusive. Much of the characteristics that describe nonmetered water systems are "too soft" for quantification and traditional statistical analysis.

Because the results for nonmetered water demand were not definitive, any inferences drawn for the nonmetered water demand must rely heavily upon circumstantial evidence. In a situation where adequate data is unavailable, circumstantial evidence may be one of few methods available for providing supporting information for hypothesized relationships. Such an approach is obviously lacking, but necessary when the data does not exist and insights into behavior can only be provided by carefully guarded inference. Contrast this to the metered water demand behavior as predicted by the models where the findings are more definitive and can be validated or refuted with greater statistical confidence.

However, despite the limitations of the study, some findings did emerge that do add new information describing water demand behavior. These findings pertain mostly to metered demand since that is what is most supported by direct statistical means. The observation that the results for metered improved throughout the regressions while those for nonmetered did not do suggest that there is a degree of difference in behavior between metered and nonmetered demand for water. The low number of nonmetered data points collected for this study is a weakness but not a deathblow. The presence of inadequate nonmetered data simply reflects the problems inherent in dealing with a nonmetered water system. This is a finding in itself that describes how utilities value and distribute nonmetered water and is indicative of how nonmetered water users might value that water.

The finding that billing frequency is significant in affecting metered water demand is a new result in water studies. Milliman (1963) suggested that billing frequency could affect water demand but did not present any supporting evidence. No other studies have published this same finding. This type of information can be used effectively by water managers if nonstructural reductions in demand on the system are desired.

Density was confirmed as an important explanatory variable for metered water demand. And, as was hypothesized, metered users do appear to respond to the weather variables, average maximum summer daily temperature and average monthly precipitation.

An "interesting" finding of the study is the significance of average charge in explaining water demand for both metered <u>and</u> nonmetered water users. This result can be interpreted as providing additional support for the idea proposed by Foster and Beattie that <u>perception</u> is critical in determining the proper price specification. For this study, average price was determined to be the proper price variable. For other studies, marginal price or some other combination of charges might prove to be the preferred price variable(s).

The finding that nonmetered water users might also respond to changes in average price provides additional, though unconventional support for the importance of perception and how it affects economic decisions. Given the low average price for nonmetered water ($0.60 per thousand gallons) in comparison to that for metered ($2.25), it is logical that nonmetered water users are shown to have a more elastic response to changes in price than metered water users (assuming that nonmetered users are price responsive). And whereas the result is anything but conclusive, it does provide discussion for the parameters of perception and economic decisions.

And finally, the derived price elasticities provide additional support for the validity of the results produced by the study. The average price elasticity value derived from the four models of -0.41 with a range of -0.34 to -0.46 for metered users is very close to the average elasticity of -0.46 for comparable studies cited in Table 4.8. This finding provides little surprise regarding the expected inelastic response to price by metered users as found in other water demand studies but does help to further affirm the validity of the models.

An average "cost elasticity" of -0.73 with a range of -0.72 to -0.76 for nonmetered users was also derived from the four models, but conclusions are more tentative. (No other studies, to our knowledge have estimated elasticities for nonmetered water demand.) Because of the lower unit price paid by nonmetered users, a relatively more elastic response to changes in the price of water is expected relative to their metered counterparts. Of course, the reliability of the derived cost elasticities for nonmetered users is more uncertain than those for metered users.

In summary, this study has provided the opportunity to re-examine the importance of perception as a key parameter in modeling for economic decisions. The possible finding that nonmetered water users appear to respond to changes in cost even though in fact their marginal price is zero, is noteworthy in describing a subset of consumers and their economic decisions that challenges traditional economic theory. Billing periods also affect perceptions in ways that changes perception are important in water demand. The weather variables also rely heavily on perception, both in the sense of perceiving the actual weather phenomenon <u>and</u> how that assessment will affect the demand for water.

So much of our dealing with water is rather different from other consumer goods. For example, a metered customer never knows exactly what the final water bill will be until at least several weeks after the consumption period. In addition, the quantities by which water is normally sold (1000 gallons or 100 cubic feet) is not typical of other consumer purchases. How many consumers really know what 1000 gallons of water can do? Translating those quantities into descriptions that consumers can more easily identify would allow for the development of a more accurate feel for the value of water. For example, informing people that 1000 gallons of water is comparable to x number of hours of lawn watering or x number of dishwashing cycles would provide a measure of consumption that is more easily comparable. Again, this relates to perception and one's ability to perceive the value of water by identifiable actions and decisions.

It is one thing to understand the importance of perception in economic decisions, and it is another to <u>realize</u> it. It appears that the value of perception and water demand has not been fully realized by the water industry. Hopefully, some of the findings presented in this study will stimulate that realization and its influence on water demand.

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APPENDICES

APPENDIX I

QUESTIONNAIRE PACKET

This appendix presents a copy of the questionnaire packet. This includes a six page survey (front and back on three pages on legal sized paper in the original) and two cover letters. The first cover letter was signed by the author and provided a brief description of the purpose of the project, the intended goals, and the requested information from the contacted water manager. The second cover letter was signed by the Department Chairman and encouraged provider participation in the survey. Department letterhead was used for the (second) cover letter signed by the Department Chairman to convey formal department support for the project.

Dear Water Manager,

I am conducting a study of the factors affecting residential water use in the southwestern United States to satisfy requirements for a graduate degree in natural resource economics. In particular, I wish to establish a clearer understanding of the diffences between metered and non-metered water demand.

Your name and address was drawn from the American Water Works Association's mailing list which does not distinguish between job titles within the management category. I wish to contact the manager or director of each water dis-tributing agency of residential and nonresidential water. If you are not that individual, would you please forward this questionnaire to him or her. In addition, I have tried to ensure that each organization receive only one survey, however, if you do receive any duplications, disregard them and please accept my apologies.

Due to the unavailability of timely and quality data, I feel it necessary to contact water companies and utilities directly. I am seeking information regarding the quantity of water consumed, rate (billing) structures, population served and conservation programs for 1984 and 1985. Individual responses will be kept confidential and results will consist of aggregated data only. A summary of this study will be made available to interested participants.

My goal is to secure as large a sample of complete data as possible. Therefore, I have tried to structure this survey so that the questions are clear and unambiguous. I have also tried to allow for personal modifications on your part in case your information does not easily conform to the structure of the question. Please feel free to add comments where they would help remove ambiguity.

I am fully aware of your own busy schedule and hope that this will place a minimum of requirements on your resources. However, if tradeoffs must be made, I would prefer to receive as complete a data as possible for 1985 rather than semi-complete data for the two years requested. If you have any questions, please contact me. Thank you.

Sincerely,

Laurie Walters, Research Assistant (303) 491-6872

Date

Dear Water Manager,

This letter is to indicate my support for Laurie

Walters's research effort and to strongly encourage you to participate in this survey.

I am confident that the information derived from this study will help to improve the understanding of the economic factors affecting water consumption. We expect the results will be useful to water utilities and their managers in planning for the future. Of course, a high participation rate will ensure a valid statistical analysis which will allow for more precise conclusions. Therefore, your participation is, once again, strongly encouraged and appreciated.

Thank you for your assistance in this matter.

Sincerely,

Ken C. Nobe, Chairman

6. HOW IS THE SEWER CHARGE DETERMINED?

7. IF THE CHARGE FOR WATER IS COMBINED WITH OTHER CHARGES ON THE BILL, IS IT IDENTIFIED SEPARATELY?

YES NO

8. HOW WERE THE POPULATION FIGURES LISTED IN QUESTION #4 DETERMINED?

city's estimate U.S. census - if so, what year? ____________

other ____

9. WATER CONSERVATION PROGRAMS

A. DO YOU HAVE A CONSERVATION PROGRAM IN EFFECT? YES NO

B. HOW LONG HAS THIS PROGRAM BEEN IN EFFECT? ____________________

C. DOES IT OPERATE CONTINUOUSLY OR ONLY DURING SHORTAGES?

D. WHAT FORM DOES THIS PROGRAM TAKE? (Circle as many options as apply)

mass media voluntary measures rationing

outdoor use scheduling educational indoor conservation devices

E. PLEASE DESCRIBE YOUR CONSERVATION PROGRAM IN A FEW WORDS:

10. WOULD YOU OBJECT TO BEING CONTACTED BY TELEPHONE FOR CLARIFICATIONS? YES NO

11. IF YOU HAVE NO OBJECTIONS, PLEASE PROVIDE A NAME, TITLE AND TELEPHONE NUMBER OF THE PERSON(S) TO CONTACT.

12. WOULD YOU LIKE TO RECEIVE A SUMMARY OF THE COMPLETED STUDY? YES NO

13. ANY ADDITIONAL COMMENTS? (PLEASE ATTACH ADDITIONAL SHEET(S) IF NECESSARY)

14. PLEASE DETACH THE TWO COVER LETTERS WHEN YOU RETURN THIS QUESTIONNAIRE. THANK YOU FOR YOUR TIME AND CONSIDERATION!

5.B. 1985 RATES AND CHARGES FOR WATER CONSUMPTION

Please identify: (1) the user classes (if they are different from the ones listed here); (2) the usual billing period (e.g. monthly, bimonthly, etc.); (3) the minimum service charge for water per billing period; (4) the minimum gallonage allowed per billing period without additional charge; (5) the type of rate structure present (constant, increasing or declining); (6) the charge per units consumed of water and the range of gallonage to which that price applies (e.g. 65¢/1000 gals. for 3500-7500 gals. consumed); (7) the last block most consumers fall into when facing an increasing or declining block rate structure (e.g. winter use-block 2/summer use-block 3); and (8) any other charges that are present on the water bill (see legend at the bottom of the chart). Please attach a copy of your rate schedule(s) if it will help to clarify the information being sought especially for instances where different rates are applied at different times of the year.

1. METERED CLASS	Usual billing period	Minimum service charge	Minimum gallonage allowed	Type of rate structure	Price in 1st block and quantity	Price in 2nd block and quantity	Price in 3rd block and quantity	Price in 4th block and quantity	Last block faced most frequently	Other charges* present on water bill
a. Single family w/in city limits										
b. Multifamily w/in city limits										
c. Other (residential										
d. Commercial										
e. Industrial										
f. Institutional & Other Gov't										
g. Municipal										
h. Irrigation										
i. Other										

*Legend for other charges: sewer(s), gas(g), electric(e), trash collection(t), none(n) and other(o)-please specify

5.B.2. 1985 NONMETERED RATES & CHARGES	single family w/in city limits	multifamily w/in city limits	other(residential)	other(nonresidential)

If nonmetered charges are listed, please describe how these rates are determined (for example, charges as a function of lot size, persons per household, number of water using devices, size of connection, etc.). It may be easier to include a copy of the rate schedule/charges for your nonmetered customers.

5.A. 1984 RATES AND CHARGES FOR WATER CONSUMPTION

Please identify: (1) the user classes (if they are different from the ones listed here); (2) the usual billing period (e.g. monthly, bimonthly, etc.); (3) the minimum service charge for water per billing period; (4) the minimum gallonage allowed per billing period without additional charge; (5) the type of rate structure present (constant, increasing or declining); (6) the charge per units consumed of water and the range of gallonage to which that price applies (e.g. 65¢/1000 gals. for 3500-7500 gals consumed); (7) the last block most consumers fall into when facing an increasing or declining block rate structure (e.g. winter use-block 2/summer use-block 3); and (8) any other charges that are present on the water bill (see legend at the bottom of the chart). Please attach a copy of your rate schedule(s) if it will help to clarify the information being sought especially for instances where different rates are applied at different times of the year.

(Fill in as many blocks as apply)

1. METERED CLASS	Usual billing period	Minimum service charge	Minimum gallonage allowed	Type of rate structure	Price in 1st block and quantity	Price in 2nd block and quantity	Price in 3rd block and quantity	Price in 4th block and quantity	Last block faced most frequently	Other charges* present on water bill
a. Single family w/in city limits										
b. Multifamily w/in city limits										
c. Other (residential)										
d. Commercial										
e. Industrial										
f. Institutional & Other Gov't										
g. Municipal										
h. Irrigation										
i. Other										

*Legend for other charges: sewer(s), gas(g), electric(e), trash collection(t), none(n) and other(o)-please specify

5.A.2. 1984 NONMETERED RATES & CHARGES

single family w/in city limits

multifamily w/in city limits

other(residential)

other(nonresidential)

If nonmetered charges are listed, please describe how these rates are determined (for example, charges as a function of lot size, persons per household, number of water using devices, size of connection, etc.). It may be easier to include a copy of the rate schedule/charges for your nonmetered customers.

4.B. 1985 WATER DELIVERY DATA (IN MILLION GALLONS)

1. RESIDENTIAL	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL ANNUAL	NUMBER OF SERVICE CONNECTIONS	POPULATION SERVED
a.Metered i.single family w/in city limits															
ii.multifamily w/in city limits															
iii.other(describe)															
iv.TOTAL METERED RESIDENTIAL															
b.Nonmetered i.single family w/in city limits															
ii.multifamily w/in city limits															
iii.other(describe)															
iv.TOTAL NONMETERED RESIDENTIAL															

Please identify whether user classes other than residential (listed below) are metered (M) or nonmetered (NM). If both metered and nonmetered customers exist in the same user classes, please split the box with a diagonal placing metered use in the top left and nonmetered in the bottom right and identify them accordingly.

2. COMMERCIAL (restaurants, offices, etc.)															
3. INDUSTRIAL															
4. INSTITUTIONAL & OTHER GOV'T (churches,schools,etc)															
5. MUNICIPAL (street cleaning, golf courses, parks, etc.)															
6. IRRIGATION (commercial farm crops & greenhouses, etc.)															
7. TOTAL METERED FOR ALL CLASSES															
8. TOTAL NONMETERED FOR ALL CLASSES															
9. TOTAL FOR ALL USER CLASSES (metered+nonmetered)															

4.A. 1984 WATER DELIVERY DATA (IN MILLION GALLONS)

1. RESIDENTIAL	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL ANNUAL	NUMBER OF SERVICE CONNECTIONS	POPULATION SERVED
a. Metered i. single family w/in city limits															
ii. multifamily w/in city limits															
iii. other (describe)															
iv. TOTAL METERED RESIDENTIAL															
b. Nonmetered i. single family w/in city limits															
ii. multifamily w/in city limits															
iii. other (describe)															
iv. TOTAL NONMETERED RESIDENTIAL															

Please identify whether user classes other than residential (listed below) are metered (M) or nonmetered (NM). If both metered and nonmetered customers exist in the same user classes, please split the box with a diagonal placing metered use in the top left and nonmetered in the bottom right and identify them accordingly.

2. COMMERCIAL (restaurants, offices, etc.)															
3. INDUSTRIAL															
4. INSTITUTIONAL & OTHER GOV'T (churches, schools, etc)															
5. MUNICIPAL (street cleaning, golf courses, parks, etc.)															
6. IRRIGATION (commercial farm crops & greenhouses, etc.)															
7. TOTAL METERED FOR ALL CLASSES															
8. TOTAL NONMETERED FOR ALL CLASSES															
9. TOTAL FOR ALL USER CLASSES (metered + unmetered)															

WATER USE SURVEY

Please read through the questionnaire before attempting to complete it since awareness of certain questions may help you to better understand the objective and scope of other questions. If you cannot answer a question, please state the reason why (for example, "not applicable" or "information not available") rather than leaving it blank. Also, please note that units of measurements may vary between questions (for example, gallons vs. million gallons). If the unit of measurement specified for a particular question is not appropriate for your data, simply cross it out and legibly insert your own. Thank you.

1. ORGANIZATION ______________________________

   MAILING ADDRESS ______________________________

   TELEPHONE ______________________________

2. ANNUAL WATER TO DISTRIBUTION SYSTEM

	1984	1985	
Water to Distribution System	________	________	million gals.
(minus) losses and unaccounted for water	________	________	million gals.
Total Water Accounted For	________	________	million gals.

3. NONMETERED (RESIDENTIAL) HOUSEHOLDS SERVED

	1984	1985
a. Single family w/in city limits	________	________
b. Multifamily w/in city limits	________	________
c. Other (describe)	________	________
d. Total nonmetered households served	________	________

4. 1984 AND 1985 MONTHLY AND ANNUAL WATER DELIVERY

The next two pages ask for data on water use (by month) for 1984 and 1985 for the different user classes along with questions relating to population served and the number of service connections per user class. If your data is not of a monthly format (for example, quarterly), simply modify the grid format to fit your data.

In order to accurately measure residential water use, I need to know the amount of water that is used in each user class that faces a separate rate structure. (Rate structures and charges are covered in question #5.) If your own accounting methods do not identify user classes exactly comparable to the ones listed here, again, simply modify the question format to accomodate your own categories, but please identify or briefly describe what those categories are. If you have residential users broken down into additional categories (other than those listed here), list those also. If data sought by a particular question are not available, please estimate them and identify them as estimates.

Below are some examples illustrating how question #4 might be completed and/or modified by a prospective participant.

EXAMPLES	JAN	FEB	MAR	. . . .	NOV	DEC	TOTAL ANNUAL .	. POPULATION SERVED
EX. 1: single family w/in city limits	580.9	593.6	600.7		585	579.9	8,843 (billion gals.)	150,000
EX. 2: other (describe) trailor courts w/city limits	8,053 (thousand gallons →	9051	8611		8423	8111	119,568)	1,600
EX. 3: we do not differentiate between these 2 categories								≈ 30,000
commercial	499.7	503.8	502		501.3	502.3	6033	(an estimate)
industrial							(million gals.)	
EX. 4: Institutional Foothills College	Done on a quarterly basis: Jan → mar ⇒		8971.5,		Oct → Dec =	8843.6	38,886 (thousand gallons)	data not available

APPENDIX II
RAW DATA

Annual data collected with the survey and used in the analysis is presented below. Utilities are not identified to ensure promised confidentiality (see Appendix 1, cover letter). The variables for which the data are presented are defined below:

CITY.	This is a seven digit number assigned to each separate reporting entity. The first two digits identify the year, 1984 or 1985 (84 or 85, respectively). The next three digits represent the assigned identification number. The last two digits indicate that this is annual data rather than monthly or quarterly, etc.
BILLING.	This value indicates the number of months between the billing of water bills (1, 2, or 3 months).
CONSERV.	This is a dummy variable indicating whether a conservation program was in existence at the time of the survey (1 = yes, 0 = no).
INCOME.	This is the average yearly income per household as calculated by the 1980 U.S. Census (dollars).
AVGBIL.	This is the average, monthly bill for water consumption for customers (dollars).
MARGPR.	This is the (average) marginal price paid for water by consumers for water demanded ($/1000 gallons).
AVGPRC.	This is the average price paid for water by consumers. This value was calculated by dividing the average water bill (AVGBIL) by the average monthly demand for water (DEMAND) per household ($/1000 gallons).
MINGAL.	The value for MINGAL reflects the quantity of water allowed for consumption before a marginal price for water is charged. The value of "50,000" was used to

represent nonmetered systems and was arbitrarily chosen as a sufficiently high number (gallons).

TIME.	This is the number of years a conservation program had been in existence at the time the survey was completed (years).
POP.	These numbers are population figures for the area serviced by the water providing entity (number of persons).
TEMP.	This is an average value of the maximum temperature for June, July, and August (degrees Fahrenheit).
PRECIP.	This is the total precipitation for June, July, and August (inches of rainfall).
DENSITY.	Density indicates the number of persons per (water consuming) household (number of persons per household).
DEMAND.	This is the average quantity of water demanded by residential household per month (gallons).

CITY	BILLING	CONSERV	INCOME
8402012	1	1	15158
8406012	1	0	14633
8411012	1	1	16423
8412012	2	1	16423
8414012	2	1	15509
8415012	1	0	12842
8415112	1	0	12842
8417012	2	1	15509
8430012	1	0	11591
8430112	1	0	11591
8431012	1	1	11591
8431112	1	1	11591
8433012	1	1	11591
8433112	1	1	11591
8436012	1	0	11501
8437012	3	1	11501
8437112	3	1	11501
8440012	1	1	12323
8444012	1	0	10112
8449012	1	0	10186
8452012	1	1	10650
8453012	1	1	9421
8458012	1	0	12846
8463012	1	0	9961
8463112	1	0	9961
8416512	1	0	11591
8416912	1	0	10149
8502012	1	1	16143
8506012	1	0	15584
8511012	1	1	17573
8512012	2	1	17573
8514012	2	1	16409
8515012	1	0	12842
8515112	1	0	12842
8517012	2	1	16409
8530012	1	0	12402
8530112	1	0	12402
8531012	1	1	12402
8531112	1	1	12402
8533012	1	1	12402
8533112	1	1	12402
8536012	1	0	12157
8537012	3	1	12157
8537112	3	1	12157
8540012	1	1	13358
8544012	1	0	10800
8549012	1	0	10807
8552012	1	1	11001
8553012	1	1	9958
8558012	1	0	12885

CITY	BILLING	CONSERV	INCOME
8563012	1	0	10140
8563112	1	0	10140
8516512	1	0	12402
8516912	1	0	10484
8417212	2	0	15509
8427012	3	0	14685
8428012	3	0	14685
8431212	1	1	11591
8437212	3	1	11501
8458212	1	0	12846
8517212	2	1	16409
8527012	6		15707
8528012	3	0	15707
8531212	1	1	12402
8537212	3	1	12157
8558212	1	0	12885

CITY	AVGBIL	MARGPR	AVGPRC
8402012	15.43	1.22	1.49
8406012	11.19	1.44	1.21
8411012	24.35	1.50	2.19
8412012	17.90	1.30	1.71
8414012	21.65	1.28	1.29
8415012	17.59	1.57	1.82
8415112	27.81	2.12	2.38
8417012	12.56	0.67	0.87
8430012	11.17	1.29	2.36
8430112	14.96	2.09	4.83
8431012	17.40	0.67	1.86
8431112	15.34	0.67	1.20
8433012	23.36	1.72	1.98
8433112	40.94	2.56	2.91
8436012	28.03	1.73	2.84
8437012	30.61	0.74	1.16
8437112	48.64	1.51	2.77
8440012	18.18	1.63	1.89
8444012	14.82	0.59	0.80
8449012	14.50	2.00	2.15
8452012	22.97	2.60	4.22
8453012	18.75	1.80	3.15
8458012	11.94	0.97	1.10
8463012	17.98	1.35	2.27
8463112	59.87	3.40	4.06
8416512	43.63	1.75	4.66
8416912	20.67	1.10	1.68
8502012	17.45	1.27	1.56
8506012	13.19	1.54	1.26

CITY	AVGBIL	MARGPR	AVGPRC
8511012	26.93	1.60	2.29
8512012	18.77	1.30	1.68
8514012	22.51	1.28	1.27
8515012	19.89	1.76	1.94
8515112	33.44	2.38	2.56
8517012	12.99	0.67	0.85
8530012	12.35	1.29	2.11
8530112	16.18	2.09	4.46
8531012	19.58	0.74	1.77
8531112	17.77	0.74	1.28
8533012	24.44	1.79	2.02
8533112	46.27	2.68	2.94
8536012	28.21	1.73	2.85
8537012	31.91	0.74	1.27
8537112	49.01	1.66	2.70
8540012	19.98	1.75	2.05
8544012	15.31	0.56	0.79
8549012	14.50	2.33	2.12
8552012	22.75	2.60	4.25
8553012	18.75	1.80	3.11
8558012	12.59	0.97	1.12
8563012	19.02	1.35	2.15
8563112	53.07	3.40	4.23
8516512	44.31	1.75	4.57
8516912	21.06	1.13	1.74
8417212	12.74	0.00	0.77
8427012	19.83	0.00	1.22
8428012	8.00	0.00	0.20
8431212	15.14	0.00	1.00
8437212	19.10	0.00	0.62
8458212	22.28	0.00	0.59
8517212	12.74	0.00	0.70
8527012	19.83	0.00	1.15
8528012	8.00	0.00	0.21
8531212	16.65	0.00	0.95
8537212	19.10	0.00	0.59
8558212	22.28	0.00	0.48

CITY	MINGAL	TIME	POP
8402012	0	4	116597
8406012	0	0	41425
8411012	3250	8	63171
8412012	5000	8	2527
8414012	2000	8	29800
8415012	0	0	34477
8415112	0	0	10240
8417012	0	1	113226

CITY	MINGAL	TIME	POP
8430012	2500	0	4601
8430112	2500	0	1990
8431012	2000	7	2576
8431112	2000	7	588
8433012	1000	1	34000
8433112	1000	1	2877
8436012	3740	0	4954
8437012	0	1	24780
8437112	0	1	3322
8440012	0	45	166636
8444012	2000	0	7000
8449012	2000	0	2365
8452012	3000	16	5889
8453012	3000	18	2500
8458012	10000	0	1437
8463012	0	0	2434
8463112	0	0	90
8416512	4000	0	1284
8416912	3000	0	10318
8502012	0	5	121619
8506012	0	0	42177
8511012	3250	9	63459
8512012	5000	9	2531
8514012	2000	8	30100
8515012	0	0	37716
8515112	0	0	10240
8517012	0	0	115990
8530012	2500	0	5096
8530112	2500	0	2268
8531012	2000	8	2607
8531112	2000	8	610
8533012	1000	2	35000
8533112	1000	2	2864
8536012	3740	0	5046
8537012	0	2	29057
8537112	0	2	2892
8540012	0	46	172356
8544012	2000	0	7000
8549012	2000	0	2484
8552012	3000	17	6045
8553012	3000	19	2500
8558012	10000	0	1667
8563012	0	0	2541
8563112	0	0	63
8516512	4000	0	1284
8516912	3000	0	10469
8417212	50000	0	323212
8427012	50000	0	4200
8428012	50000	0	5000
8431212	50000	7	44097

CITY	MINGAL	TIME	POP
8437212	50000	1	33148
8458212	50000	0	3511
8517212	50000	1	321631
8527012	50000	6	4200
8528012	50000	0	5000
8531212	50000	8	45522
8537212	50000	2	31256
8558212	50000	0	3280

CITY	TEMP	PRECIP
8402012	87.50	7.37
8406012	83.80	5.12
8411012	80.87	7.29
8412012	80.87	7.29
8414012	84.60	6.57
8415012	83.80	5.12
8415112	83.80	5.12
8417012	84.60	6.57
8430012	74.73	8.66
8430112	74.73	8.66
8431012	82.73	4.76
8431112	82.73	4.76
8433012	86.07	5.04
8433112	86.07	5.04
8436012	82.73	4.76
8437012	86.17	4.59
8437112	86.17	4.59
8440012	81.70	9.54
8444012	79.17	2.36
8449012	86.50	7.18
8452012	83.97	4.94
8453012	84.47	4.00
8458012	83.73	6.70
8463012	77.50	6.16
8463112	77.50	6.16
8416512	86.07	5.04
8416912	90.13	8.93
8502012	86.37	7.37
8506012	83.93	4.97
8511012	83.43	4.69
8512012	83.43	4.69
8514012	85.33	5.45
8515012	83.93	4.97
8515112	83.93	4.97
8517012	85.33	5.45
8530012	77.20	4.88
8530112	77.20	4.88

CITY	TEMP	PRECIP
8531012	83.57	6.72
8531112	83.57	6.72
8533012	84.63	3.16
8533112	84.63	3.16
8536012	83.57	7.23
8537012	86.40	4.74
8537112	86.40	4.74
8540012	82.73	7.26
8544012	80.30	3.06
8549012	85.73	2.63
8552012	85.30	3.77
8553012	88.27	1.23
8558012	85.83	2.61
8563012	85.83	2.61
8563112	85.83	2.61
8516512	84.63	3.16
8516912	90.60	5.87
8417212	84.60	6.57
8427012	77.33	6.72
8428012	77.33	6.72
8431212	82.73	4.76
8437212	86.17	4.59
8458212	83.73	6.70
8517212	85.33	5.45
8527012	80.43	3.62
8528012	80.43	3.62
8531212	83.57	6.72
8537212	86.40	4.74
8558212	85.83	2.61

CITY	DENSTY	DEMAND
8402012	2.60	10360
8406012	2.58	9251
8411012	4.50	11097
8412012	3.50	10471
8414012	4.12	16767
8415012	3.28	9674
8415112	3.79	11661
8417012	3.72	14427
8430012	3.13	4740
8430112	3.13	3098
8431012	2.80	9357
8431112	2.80	12817
8433012	3.33	11816
8433112	3.33	14053
8436012	3.79	9881
8437012	4.38	26396

CITY	DENSTY	DEMAND
8437112	4.38	17579
8440012	2.51	9640
8444012	3.04	18609
8449012	2.37	6729
8452012	3.00	5438
8453012	3.33	5949
8458012	2.89	10899
8463012	2.48	7935
8463112	2.50	14743
8416512	4.01	9359
8416912	3.50	12299
8502012	2.60	11191
8506012	2.53	10464
8511012	4.50	11776
8512012	3.50	11176
8514012	4.05	17782
8515012	3.35	10258
8515112	3.78	13085
8517012	3.81	15308
8530012	3.13	5851
8530112	3.13	3632
8531012	2.80	11061
8531112	2.80	13891
8533012	3.33	12068
8533112	3.33	15727
8536012	3.76	9907
8537012	4.46	25185
8537112	4.47	18153
8540012	2.50	9737
8544012	3.04	19330
8549012	2.37	6853
8552012	3.00	5357
8553012	3.29	6020
8558012	2.82	11280
8563012	2.53	8833
8563112	2.63	12559
8516512	4.00	9694
8516912	3.50	12095
8417212	3.72	16465
8427012	3.65	16213
8428012	4.00	40064
8431212	2.80	15182
8437212	4.38	30832
8458212	2.89	37562
8517212	3.72	18295
8527012	3.61	17318
8528012	9.19	38633
8531212	2.80	17460
8537212	4.46	32106
8558212	2.82	45982