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COMMUNITY WATER DEMAND IN TEXAS

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ABSTRACT

Solutions to Texas water policy and planning problems will be easier to identify once the impact of price upon community water demand is better understood. Several important questions cannot be addressed in the absence of such information. This study combines monthly water use reports, Census information, weather data, and water rates for more than two hundred Texas communities. The study period is the five years for which data is most recently available, 1981-85. Descriptive and statistical results concerning community water demand are generated with this data. Notable findings are (1) a new climate variable is developed which has good performance in demand functions; (2) Texas consumers respond to water price with the average price specification being preferred over the marginal price alternative; (3) price elasticities vary during the year with the highest price sensitivity occurring in summer months; and (4) sewage rates which depend upon water consumption represent a statistically significant component of water price. The quantitative results of this study enable many potential applications for solving state and local problems.

COMMUNITY WATER DEMAND IN TEXAS

I. INTRODUCTION

Increased population, increased population growth, and vigorous economic development are well documented Texas realities during the past two decades. This growth has been responsible for a great amount of pressure on the state's natural resource base. These pressured resources certainly include the water, soil, air, land, and mineral resources of the state. Because the potential implications of these additional pressures are both qualitative and quantitative, public planning for the use of the state's natural resources is complex.

The purpose of this research is to address the issue of water demand within Texas communities and to investigate selected demand factors. The information resulting from this research will enable state and local planners to be better equipped to handle issues of water allocation within the state. Only through careful examination of water demand by individual sectors and of water supply from specific sources can reasonable approaches to allocating scarce water supplies become available. The impact of water price on sectoral water demands is particularly crucial because it has been neglected. The inclusion of price means that, unlike other studies, this research will identify community water demand instead of water use. The implications of this distinction are critical for public planning and are discussed later.

While the effect of price on the state's largest user of water, irrigated agriculture, has been the subject of available research, the effect of price on the state's top priority water use, domestic and municipal, has received little attention. Because of the relative abundance of water supplies in many areas and the relative price sensitivities of agricultural and municipal water uses, emphasis upon the price sensitivity of irrigation water demand has been justifiable. However, recent and future increases in water scarcity and some recent changes in federal water policy have altered this situation.

The forthcoming study justification" (below) indicates that a generalized community water demand function will provide the means to:

- project future water demand for specific communities;
- value enhancements to municipal water supplies;
- establish rate structures for allocating limited water supplies;
- evaluate water conservation measures;

- estimate the municipal costs and benefits resulting from proposed interbasin/intersectoral water transfers; and
- examine rate structures including peak-load pricing.

Report Format

After introductory material concerning the need for and uses of this study and a brief literature review, the remainder of this report is composed of three major sections followed by conclusions. A description of data collection procedures and sources is contained in Section II. Basic descriptive information using the collected data is presented in Section III. The purpose of Section III is to determine trends in water use and rates as well as to illustrate certain aspects of the Texas setting. The primary analyses are in Section IV. Rather than restating the many findings of this study, the concluding section, Section V, contains directions and suggestions for the application of this work.

In addition to research findings reported in the main body of the text, secondary information is presented in several appendicies. The purpose of the appendicies is to provide information necessary for the above applications. *Readers who are most interested in the empiricism of this study can omit the detailed justification and background information by turning to the "Related Research" section on page 7 or the description of data sources beginning on page 10.*

Study Justification

Population Growth and Economic Activity

The population of Texas grew from 11,198,655 persons in 1970 to 14,228,383 persons in 1980. This 27 percent growth in population was the highest in the nation, and only California added more people (Skrabanek and Murdock 1981). Population growth during this same period was projected to be 19.6 percent, thus emphasizing the unexpected proportions of this increase (Texas Water Development Board 1977, p. II-40). Texas is now the third most populous state and is expected to rank second by 1990. The population of Texas' villages, towns, and cities increased from 9,178,577 in 1970 to 11,468,410 in 1980 (Murdock et al. 1981). This represents a 25 percent community growth rate during the past decade. Over 80 percent of Texans lived in these communities during 1980.

Past and present population growth in Texas has been greatly spurred by a favorable economic climate. The number of employees working in Texas farms and firms grew 65% from 1970 to 1980 (U.S. Department of Commerce 1971, 1982). Personal income (expressed in 1972 dollars) in Texas expanded from 42.9 billion dollars in 1970 to 76.1 billion dollars in 1980 (U.S. Department of Commerce 1981, p. 428). This 77.4

percent increase in personal income was bettered by only four states: Alaska, Arizona, Nevada, and Wyoming. Per capita income (1972 dollars) grew from $3,823 to $5,336 during this same period.

Increases in personal income must clearly be the result of expanding economic activity in the state. One indicator of this activity is the "value added" which can be attributed to agricultural, commercial, and industrial productivity. In Texas, value added was over 33 billion dollars in 1977. The three largest contributors to this amount were chemicals, petroleum, and nonelectrical machinery production. The level of value added in 1977 had tripled since 1967, and no other industrialized state could match this increase (U.S. Department of Commerce 1981, pp. 782-3).

Continued population and economic growth seems virtually guaranteed on the basis of momentum alone. However, water scarcity will limit growth in some areas of the state. Future municipal and industrial demands for water resources will certainly surpass current demands by ever-increasing margins. Regions presently possessing excess water supplies will find their surpluses eliminated, and other areas will experience still greater pressures for their limited water resources.

The Relative Importance of Community Water Use

Based on revised U.S. Geological Survey information, communities do not use a large percentage of Texas' water supplies (Murray and Reeves 1977). Municipal and domestic water use represented only sixteen percent of the total Texas water use in 1980 (Table 1). However, in terms of general public welfare municipal and domestic water use is a very important category of water use. Furthermore, the population figures previously reviewed suggest that water demand by communities will increase substantially during the future as it has during the past.

Table 1. Water Use in Texas, 1980 (acre-feet per year)

Sector	Consumptive Use
Municipal and Domestic	2,813,182
Manufacturing	1,519,992
Mining	239,076
Steam-Electric	330,057
Agriculture	12,950,357
Total	17,852,664

Source: *Water for Texas*, V. 1, p. 25.

Because of the importance attached to household water uses and, therefore, to the availability of water resources for household use, domestic and municipal water uses have the highest priority within the state's preference system. This system, which was adopted in 1931, allows for higher priority water users to supersede water rights held by other water users regardless of the relative dating of these rights. Eminent domain condemnation is required for this action, and compensation must be paid (Cox 1982). However, condemnation of post-1931 water rights for domestic and municipal use by any city or town does not require compensation.

Economic Considerations

Even in the absence of legal advantages granted to domestic and municipal water uses by state law, growing community water demand would certainly result in reallocations. As local water supplies become more scarce, that is, as demands increase relative to supply, domestic and municipal water users will continue to value water more highly than the state's largest water consumer, irrigated agriculture. Therefore, as community water demand increases, communities will attempt to purchase the water rights held by agriculture.

It is very notable in this context that recent changes in federal water policy require the incorporation of "water conservation" in the economic evaluation of proposed federal projects for augmenting municipal and industrial water supplies (U.S. Water Resources Council 1979, pp. 72978-9). Water conservation is interpreted by academicians as "the more effective utilization of existing supplies" (Moomaw et al. 1980) which is tantamount to requiring economic efficiency in water use and allocation. It has been demonstrated that economic efficiency in municipal and industrial water use cannot be assessed without community water demand functions (Griffin and Stoll 1983). Using this information, consumers' "willingness-to-pay", a measure of economic benefits, for additional water supplies can be calculated.

Use of demand functions to value additions to water supplies is a substantial improvement over the more traditional method.

> The conventional approach to urban water planning is narrowly confined to analyzing the technical alternatives that can be used to augment supplies. This approach is based upon the premise that water is necessary for life. Hence, price-demand relationships are ignored, and forecasts of water demands are, in effect, water "requirements" (Hanke and Davis 1971, p. 555).

Economists emphasize the serious limitations of the so-called "requirements approach." The primary fault of this approach is that it limits decisions makers to "supply management" and ignores the role of pricing in consumption decisions. "Traditionally, water utility managers have adjusted water quantities rather than prices as changes in demand occurred" (Grunewald et al. 1976, p. 952). Analysis incorporating the specification of demand functions includes a role for *both* price and supply management. Such analysis can be used to identify that combination of price and supply management which will maximize net gains for consumers. Compared to demand analysis, the requirements approach to water supply planning results in lower net benefits, higher average water charges, greater water consumption, and the construction of larger reservoirs (Carey and Haan 1976). Moreover, for prospective projects which are under study, the requirements approach overestimates benefits (U.S. Corps of Engineers 1980, p. III-138).

Even in the absence of recent federal rule changes, the utilization of community demand functions represents a very valuable approach to water supply planning. This approach can be advantageously adopted for the evaluation of community water projects (using either surface water or groundwater) which are not necessarily subject to federal rules. The advantages of this procedure result, largely, from the fact that it generalizes the requirements approach. Communities need to be aware of the full range of technical and economic alternatives for the efficient utilization and development of existing and available water supplies. Given (a) the reduced role of the federal government in constructing new water projects, (b) the increased cost of building reservoirs, drilling wells, and installing water transmission facilities, and (c) the fact that the best sites for water projects are already developed, communities can no longer afford to restrict their attention to purely technical alternatives for enhancing water supplies. With a rapidly increasing population, an expanding economy, and physical limitations on available water resources, the requirements approach to water supply planning is no longer tenable.

As technological alternatives (supply management) for remedying water supply shortages become more costly and less realistic, new approaches to allocating scarce water resources will have to be identified and utilized. A large array of such approaches warrant consideration. In competitive markets, price is the device which balances supply and demand, so it is natural to employ appropriate water charges to allocate available water resources in many instances. Economists have long argued for price as an important public tool for managing municipal water supplies (Hanke and Davis 1973). But what price is necessary to allocate a limited water supply within a given community? Such questions cannot be answered without knowledge of the community's demand for water at various prices. Thus, community water demand functions can be used to evaluate alternative rate structures for their ability to ration available water supplies. In addition, the impact of different rate structures on various income groups can be examined if income is included as an explanatory variable in the demand function. Thus, the equity of alternative rate proposals can be identified if demand functions are appropriately specified. The effect of alternative water rates on expected total revenue for a water utility can be easily evaluated when the demand function is known. Most communities would find this to be very useful information.

As a related matter, water management plans are usually scaled to handle peak loads which typically occur during summer months. Therefore, the marginal costs of water are higher during the summer. Under these circumstances it can be economically efficient to establish rate structures which vary during the year so as to better allocate supplies and reflect actual costs (Hanke and Davis 1973, Feldman 1975). The design of TOY (time of year) rate structures and their impacts upon water consumption, water utility revenues, and household water costs can be examined if the developed water demand function includes time or a time variant as an explanatory variable.

Price is not the only variable available to public planners attempting to encourage effective water use. Water pressure control, leakage control programs, education campaigns, rationing, and plumbing codes may all be viable methods of inducing water conservation (U.S. General Accounting Office 1978, American Water Works Association 1984). Advantageous public programs incorporating one or more of these alternatives (as well as metering) can often be formulated. However, a logical appraisal of the alternatives is usually a difficult endeavor requiring several major information inputs (Baumann, Boland, and Sims 1980). The benefits and costs of adopting various measures will include both economic and noneconomic impacts. While the noneconomic impacts are typically difficult to quantify, the economic impacts can be assessed if the needed supply and demand relationships have been identified.

One obvious application of water demand functions is for projecting future water use. The need for water use projections by public planners defines a crucial use of the research undertaken here. Several methodological alternatives exist for projecting water use, and they may differ with respect to their assumptions, generality, simplicity, reliability, data requirements, as well as many other factors. Research funded by the Corps of Engineers has resulted in an itemized comparison of the available water use projection methodologies. Major disadvantages and deficiencies in traditional methods were found. It was concluded that "*Demand models (functions) offer the possibility of the best obtainable estimates of future water use, provided the models are carefully developed and applied*" (Boland, Baumann, and Dziegielewski 1981, p. III-33, emphasis added).

As structural changes in population, commerce, technology, and the demand for goods and services occurs, the demand for water by various sectors of the economy will change as will the location of these demands. If water was a purely private good devoid of externality relationships, then relative movements in demand could cause water to be reallocated to its highest valued uses. However, water is not a good which is well suited for uncontrolled market allocation, and allocative institutions must be carefully designed and monitored. Public officials must be in a position to evaluate and reevaluate the merit of existing water supply allocations as structural changes take place over time.

Planners must have the information needed to formulate and evaluate alternative intersectoral and interbasin transfers of water resources so that limited supplies can be best committed to various needs. Such transfers have the potential to affect all major sectors of the economy. Economic assessment of prospective benefits and costs requires some concept of water demand by each affected sector of the economy. Many different levels of aggregation are possible. However, if we look upon communities as separate sectors, then it is clear that intersectoral or interbasin water transfers may influence some communities negatively and others positively. Knowledge of these respective costs and benefits would certainly be important in deliberations over proposed transfers. A methodologically sound technique for quantifying these impacts is available, and this technique requires community water demand functions as input information (Griffin and Stoll 1983). Therefore, research to identify community water demand relationships will permit the economic measurement of community benefits and costs resulting from proposed transfers of water resources.

Related Research

Econometric analysis of community water demand has been performed previously by many social scientists in many parts of the United States. However, little research of this type has been conducted for Texas communities. Most of what has been done concerns water use rather than demand. The first example of published research relevant to Texas pertains to a statistical time-series analysis of community water *use* by Maidment and Parzen (1981). Maidment has since led other efforts which also address water use rather than demand (Maidment, Miaou, and Crawford 1985; Maidment and Miaou 1986). Murdock et al. (1986) have explored extensively the impacts of various demographic and socioeconomic variables upon community water use in Texas. Three month summer and winter water use variables were computed for 677 communities and used as dependent variables. Independent variables were obtained from 1980 Census data. Because water price was not included as an explanatory variable, these analyses do not address the question of water demand and are not applicable for the uses motivating the present study.

Nieswiadomy and Molina (1988) have employed microdata for 1981-85 summer months in the City of Denton, Texas to estimate water demand. Microdata uses observations for individual households. While microdata can enable interesting findings because of the absence of aggregation, the narrow focus of these results (one city, one season) prohibits a reliable generalization to a community water demand function for Texas. The Nieswiadomy and Molina study does not offer, unfortunately, interesting comparisons to this report because of their peculiar findings (e.g. positive or insignificant price coefficient depending on estimation procedure).

Some of the earliest notable examples of community water demand analysis were conducted by Howe and Linaweaver (1967), Wong (1972), and Young (1973). Howe and Linaweaver assembled and analyzed data from 21 metered areas in the U.S. Wong's analysis pertained to Chicago and surrounding areas, and Young studied the water demand of Tucson. Since the publication of these works, many similar studies have been completed. These studies differ in terms of region, time period, chosen explanatory variables, variable specification, functional form, level of aggregation, and data sources, among other things. Several major conclusions have emerged from these efforts and are now widely accepted. The following paragraphs attempt to summarize the most useful findings.

Water utility rates have been found to be an important determinant of water use wherever metering has been in effect. Thus, community water demand is price responsive. The large number of econometric studies incorporating price as an explanatory variable has allowed several authors to tabulate previous results for the purpose of comparing the relative impact of price (Cassuto and Ryan 1979; Danielson 1979; Camp 1978).

Price responsiveness is often measured by price "elasticity" which is defined as the percentage change in use brought on by a one percent change in price. Because water price and water use move in opposite directions, price elasticities are negative. Price elasticities for water demand are generally found to be low (between 0 and -1) but quite significant in the statistical sense. Where research has been able to separate in-house water demand from the demand for water for lawn and garden irrigation, it has been determined that outside water demand is much more price sensitive — with price elasticities less than -1 (Howe and Linaweaver 1967; Danielson 1979; Erlenkotter et al. 1979). Furthermore, in areas where groundwater is being used price responsiveness is greater, perhaps because the added expense of groundwater implies that a different segment of the demand curve is being examined.

Income elasticity has also been investigated in many studies (e.g. Wong 1972, Gibbs 1978, Foster and Beattie 1979, Billings and Agthe 1980). Because increased income should cause increased water consumption, income elasticity is expected to be positive. Wherever income was found to be a statistically significant variable in estimated water demand functions, the income elasticity was positive. However, some studies have found income not to be uniformly significant, possibly because water costs have historically been such a trivial part of household budgets.

Some studies, particularly earlier ones, utilized average water price as the observed exogenous price variable (Young 1973, Grunewald et al. 1976, Foster and Beattie 1979). Because of block rate structures and minimum bills, average water price is different from marginal water price within all communities. It has been argued that average water price is inappropriate for demand estimation (Gibbs 1978; Colander and Haltiwanger 1979; Billings and Agthe; Griffin, Martin, and Wade 1981) and that the use of average water price will result in water demand functions which are overly sensitive to price (Gibbs 1978, Billings and Agthe). Subsequent research concentrated upon multiple price variables incorporating features from both average price and marginal price specifications. A variable originated by Nordin (1976) has been used as a price variable in multiprice models by several authors.

Theoretical models of utility maximization under perfect information show that Nordin's difference variable captures the income effect induced by changes in inframarginal rates (Opaluch 1982, 1984). Utility-maximization models have been deployed to promote one specification over others, but all such theoretical models have unfortunately endowed the consumer with perfect information in a situation absent transaction costs. Because of our concern for this issue, such an approach is not presented here. The most recent writings appear to accept the notion that choice among alternate price specifications is a matter awaiting empirical, rather than theoretical, resolution (Foster and Beattie 1981, Opaluch 1982, Charney and Woodard 1984). Theoretically, the parameter estimate for Nordin's difference variable should equal the parameter estimate for income, but empirical evidence has never supported this hypothesis (Billings 1982, Jones and Morris 1984, Chicoine, Deller, and Ramamurthy 1986). The Denton study by Nieswiadomy and Molina did not find this variable to be statistically significant.

Econometric investigations of community water demand employ either one or both of two different data types. Cross-sectional data is information on actual water use for different locations during the same time period. Time-series data are observations on actual water use for the same location during different time periods. Pooled data includes both cross-sectional and time-series data, i.e., different locations in different years. The appropriateness of cross-sectional versus time-series data has been the source of some discussion in the community water demand literature. Time-series data maintain structural rigidities inherent to the location being studied which may limit the application of results to other locations. "Cross-sectional data capture long-run structural differences and are primarily useful for estimating long-run demand curves relevant for planning decisions for developing areas (Colander and Haltiwanger 1979, p. 1275)." Thus, both data types have merit, and the best-suited data type seems to be dictated by the use(s) to be served by research results. Cross-sectional data is more appropriate for planning in rapidly developing areas, while time-series data is to be preferred for planning in areas which are largely developed. These considerations also suggest that cross-sectional water demands should be more responsive to price than are time-series water demands (Colander and Haltiwanger 1979).

II. DATA

Data for this analysis are taken from four major sources. Three sources pertain to secondary data. Each source is discussed following the description of sample selection. Then, each elemental variable employed in the forthcoming statistical analyses is defined, and specific data sources for each variable are identified.

Sample Selection

This research focuses upon all Texas water systems providing public water supplies for sale except those which are very small. All systems are required to make annual reports of water use to the Texas Water Development Board (TWDB). Based upon preliminary discussions with TWDB personnel, the ad hoc decision was made to exclude any water systems having fewer than 500 connections. These small water systems are excluded because the special problems they face are thought to inject a high amount of "noise" into reported data. Among the 1167 systems identified by the TWDB as having 500 or more connections, there are 27 not-for-sale systems (13 U.S. military bases, 13 prisons, and 1 park).

Given the unavailability of truly recent water use data and the desirability of a climatically rich time-series, the selected period of analysis includes five years, 1981-1985 inclusively. More recent data on water use was unavailable as of March 1989. The study period does not commence before 1981 because of the unbalancing impact of including more than one drought year (1980 and 1984).

Data Collection Overview

Survey

A survey was designed to obtain water and sewer rates for the study period and current indirect tax and daily capacity for each water system. The survey is shown in Appendix A.

On July 24, 1987 the survey was mailed to the 1140 water systems having more than 500 connections. A second survey was also sent to nonrespondents on August 31, 1987. Of the 1140 surveyed systems, 543 (47%) replied to the survey. Telephone surveys were used to follow up on a portion of the 543 systems to confirm some answers on the surveys. Many follow-up telephone calls were made to clarify ambiguities, especially regarding sewer rates (the complexity of sewer rates was poorly anticipated by the survey design). Following the telephone survey, it was determined that 479 water systems completed the survey adequately.

The institutional and economic characters of reporting water systems are quite diverse. Towns, cities, irrigation districts, municipal utility districts, rural water supply districts, and river authorities responded to the survey. All of the respondents supply residential water, but both supply and demand conditions are highly variable. To produce a reasonably homogeneous sample for estimating community water demand in Texas, we define *community* to be any water system providing both water and sewer services. Evidence of such services is taken to be the presence of both water and sewer rates in returned surveys. Based on this criterion, there are 272 communities among the 479 usable survey responses.

Texas Water Development Board

Two sets of data were obtained from the TWDB. These are municipal water distributions and water use histories for the period 1980 to 1985.

TWDB data is used to compute per capita monthly water use and the percentage of water supply derived from groundwater sources. Incomplete TWDB data eliminates 11 communities from the sample leaving 261 communities. Missing Census data (discussed in the next section) further reduces the number of communities to 255.

From the data collection procedure, the total of 255 communities are obtained as the primary sample. To reduce the potential influence of unreliable water use data, a portion of the sample is deleted according to the following procedures. One of the survey questions asked respondents to identify months during which demand was not satisfied. Based on responses to this question, 197 observations are deleted from the sample. Gallons per capita per month (g/c/m) and per day (g/c/d) are then calculated for the remaining 255-community, five-year sample (14,377 observations). The range of results is extreme, varying from 3 to 1631 g/c/d. Monthly means exceed medians from 330 to 778 g/c/d in all twelve months. This indicates the presence of some skewness in the data. For winter months approximately 5% of the data is less than 2,300 g/c/m. This information is employed in the following deletion rule. Nineteen communities are entirely deleted from the sample because of exceedingly low reported water use (less than 2,300 g/c/m) in more than 10% of the months reported. Similarly, for summer months approximately 5% of the sample exceeds 13,600 g/c/m. Accordingly, seventeen communities are entirely deleted because of exceedingly high reported water use (more than 13,600 g/d/m) in more than 10% of the months reported. After deleting 34 communities (two communties were deleted for both high and low water use reports), monthly means exceed medians from 200 to 490 g/c/d in every month.

It is not surprising that 31 of the 34 deleted communities are quite small (1980 population less than 10,000). Notably, Houston is one of the communities deleted for exceedingly high reported water use. No attempt was made to determine reason(s) behind these strong outliers. Some of these extremes may be caused by reporting errors, but more likely causes relate to special local circumstances. In addition to the global deletion of an entire community from the sample, certain months are also deleted for individual communities. These observations (19) are deleted because calculated g/c/m quantities are sharply divergent from those for other months reported by the community.

All of the above exclusions should improve the reliability of forthcoming results. Our subjective judgement is that we have only removed the "worst" of the data and that more deletions may have been desirable. That is, if the deletion procedure erred, it erred on the side of accepting poor data. No statistical analysis was conducted prior to these deletions, so the impacts of these exclusions remain unknown.

The final dataset includes information for 221 communities. These communities are listed in Appendix B, Table B-1. Because of missing water use, rates, or weather information, there is not five years of data for every community. The average record is 4.5 years per community. The data is monthly, and there are 12,050 observations in the final dataset.

U.S. Census

The Texas Natural Resources Information System (TNRIS) provided two sets of data. One is 1980 Census information published by U.S. Department of Commerce in 1982. The other is National Weather Services (NWS) data for climate information. Census data provided per capita income and the percentage Spanish population for each community in the sample. Average household size across all communities was also obtained from Census Data. Unavailable Census data (mentioned previously) resulted in the deletion of six communities.

Climate

NWS data from all Texas weather stations was acquired from TNRIS for daily precipitation, daily maximum temperature, and daily minimum temperature, for the years of 1981 through 1986. In conjunction with the NWS climate data, the report *Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1951-80* (National Oceanic and Atmospheric Administration NOAA 1982) was obtained after pretest analyses were completed (discussed by Griffin and Chang 1988). NOAA information identifies the average annual precipitation of individual weather stations over a 30-year period (1951-80).

The following criteria were adopted to match each community with a weather station. For NWS daily data on precipitation and temperatures, a weather station was matched to a community if the weather station was located in the community and if there were less than 8 months of missing weather data for the five year period. If more than 8 months of data were missing, the closest alternative weather station was chosen, employing latitude and longitude of the weather stations. If the community did not have a weather station at all, the closest weather station was selected using the same method. For NOAA's average precipitation data, it was attempted to employ each community's matched NWS weather station. In some cases NOAA data does not include a weather station because of an insufficient record for obtaining a 30-year average. In these cases communities are matched with the closest alternative weather station using the latitude and longitude method. Corresponding weather stations are identified in Appendix B, Table B-1.

Variable Descriptions

General definitions and calculation methods for each fundamental variable are provided in this section. These variables are either directly used in forthcoming statistical analyses or are used to formulate new variables.

- Per Capita Daily Water Use: From TWDB data, annual water use was obtained in acre-feet along with 12 monthly fractions totalling to 1. After converting annual water use to gallons, the monthly fractions are used to compute system water use for each month. The monthly water use then is divided by the projected population for that water system, which the TWDB had projected on an annual, not monthly, basis. This yields the estimated monthly per capita water use for each community. Division by the appropriate number of days identifies daily water use per capita.

- Household Average Price: Using Census data for each community, the number of people occupying nonrental housing units is divided by the number of occupied nonrental housing units to obtain average household size. Results range from 2.2 to 3.7 persons per household. Taking a housing unit-weighted mean identifies a statewide average 2.84 persons per household. Per capita daily water use is multiplied by 2.84 and the number of days in the month to estimate monthly household water use. Using survey-obtained rate information, both water and sewer bills are calculated for the level of household water use. These two bills are added and divided by household water use to determine average price. This procedure is performed for each of the 60 months and each of the 221 communities.

- Household Marginal Price: Using monthly household water use, marginal water and marginal sewer prices are obtained from the appropriate blocks of the rate information. These two prices are added to obtain marginal price. This procedure is also performed for all months and communities.

- Per Capita Income: Using only data from the *Census of Population and Housing, 1980*, which was obtained from TNRIS on magnetic tape, aggregate household income in 1979 was divided by total population in the community. Because income data is not available for each year of the study period, per capita income is time invariant and varies only cross-sectionally. Data for this variable and other time-invariant variables is listed in Appendix B, Table B-2.

- Percentage of Population with Spanish Origin: Using the Census data, each community's Spanish population is divided by the total population to obtain the percentage of population with Spanish origin. Like the per capita income variable, this variable takes on the same value for all months and years for a given community. See Appendix B, Table B-2.

- Monthly Average Temperature: Using the NWS data, daily maximum temperature and minimum temperature are added and divided by two to approximate an average temperature. The daily average temperature is then averaged for each month.

- Number of Days without a Significant Rainfall: From the daily precipitation data, the number of days with at least 0.25 inches of precipitation was counted in every month of the study period. This was then subtracted from the number of days in the month.

- Average Annual Precipitation: This variable was directly acquired from the NOAA data. Because this is a long term variable, no time-series variation exists in these data. See Appendix B, Table B-2.

III. DESCRIPTIVE STATISTICS AND TRENDS

As a first step in contributing to the knowledge of community water demand in Texas, it is useful to investigate fundamental data. Such an investigation can produce important insights into patterns of water use and its determining factors. In addition to providing raw information for planning, suggestions for econometric work can often be obtained.

While the several data variables just defined offer many opportunities for examination, concentration is focused upon water use and water price. Of the several possible approaches for viewing these two items, this section presents an analysis dimensioned by time (both months and years), community size (population), and space (region). Historical water consumption is first inspected to determine how it has varied from month to month, from year to year, across communities of different size classifications, and across major regional delineations in Texas. Water price is then subjected to the same inquiries while separately examining both water and sewer components of rate structure, marginal prices, and average household bills.

Water Consumption

The most basic and important of the variables defined in Section II is water consumption per capita per day. The most fundamental questions concerning this variable pertain to seasonality, annual trends, and possible differences among the many Texas communities.

Water Use by Year

Monthly and annual per capita water use by the average Texan[1] in each year is shown in Figure 1. Water consumption follows a typical pattern which is high in summer months and low in winter months. The rather high 1984 consumption from April to July reflects the summer drought of that year and leads to the highest annual consumption during five years of the study period (186 g/c/d). This high level of consumption also occurred in 1982 because of demand during June, July, and August. August 1985 produced the highest single month of water consumption (275 g/c/d) — almost twice as much as the average winter consumption for the five years. Average winter (December through February) consumption is 145 g/c/d, and average summer consumption (June through August) is 234 g/c/d.

Water Use by Size

Communities are grouped into five ad hoc, population size categories for the purpose of analyzing possible differences across size. Most of the sample falls in the smallest classification.

Size	Population	Numbers (%)
A	0 - 10,000	170 (72.3%)
B	10,000 - 25,000	31 (13.2%)
C	25,000 - 50,000	11 (4.7%)
D	50,000 - 100,000	11 (4.7%)
E	100,000 -	12 (5.1%)

Monthly and annual water consumption by size is shown in Figure 2. The monthly nature of water consumption is depicted in the same way as the analysis of water consumption per year. Middle-sized communities (size C) appear to consume the least amount of water among the five groups, but the small number of communities in this group probably limits the statistical significance of this finding. Secondly, small communities (size A) consume more water than the next two larger groups. This is noticeable from spring until the late summer months. Perhaps garden agriculture is responsible for the high consumption in this size category. The pattern of water use is very similar for cities in the two largest classifications.

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[1] Similar information in this section pertains to average individuals rather than average communities. The former is a population weighted mean across communities.

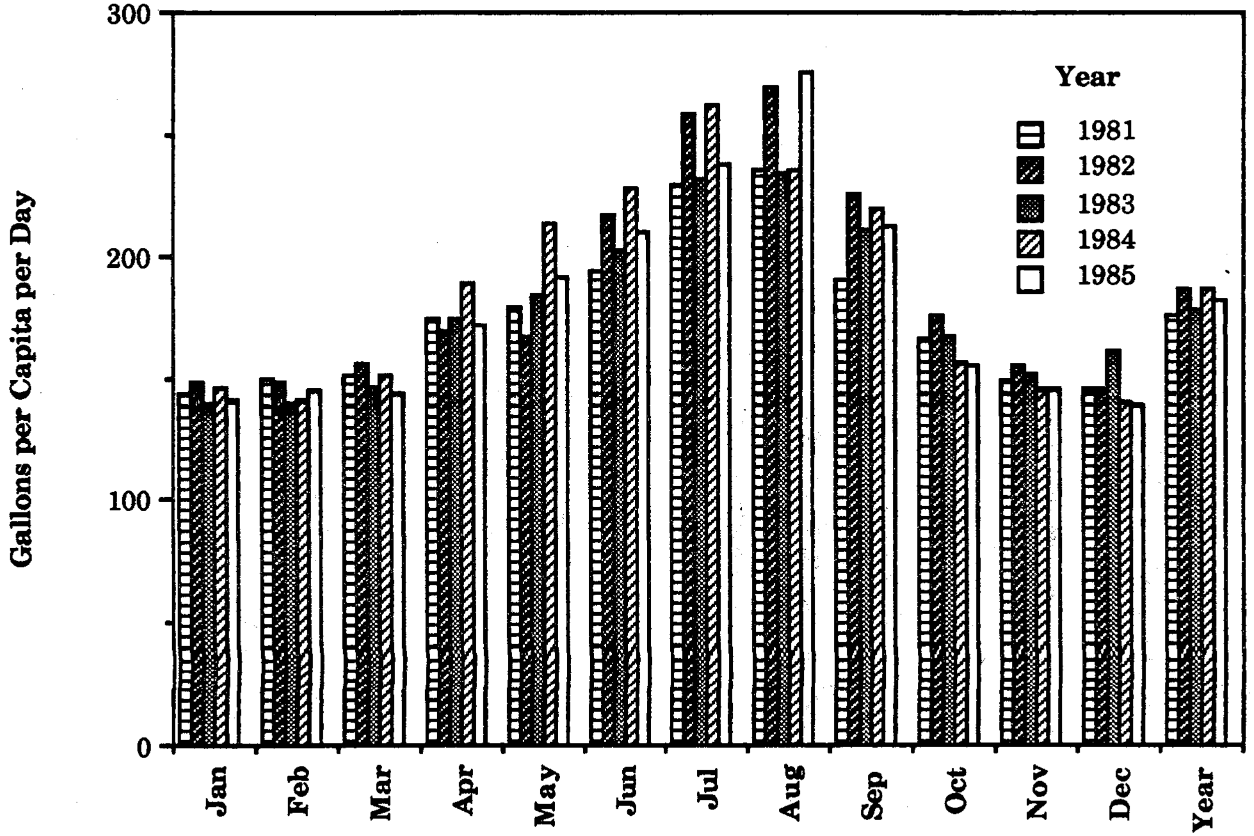

Figure 1. Monthly and Annual Water Use by Year

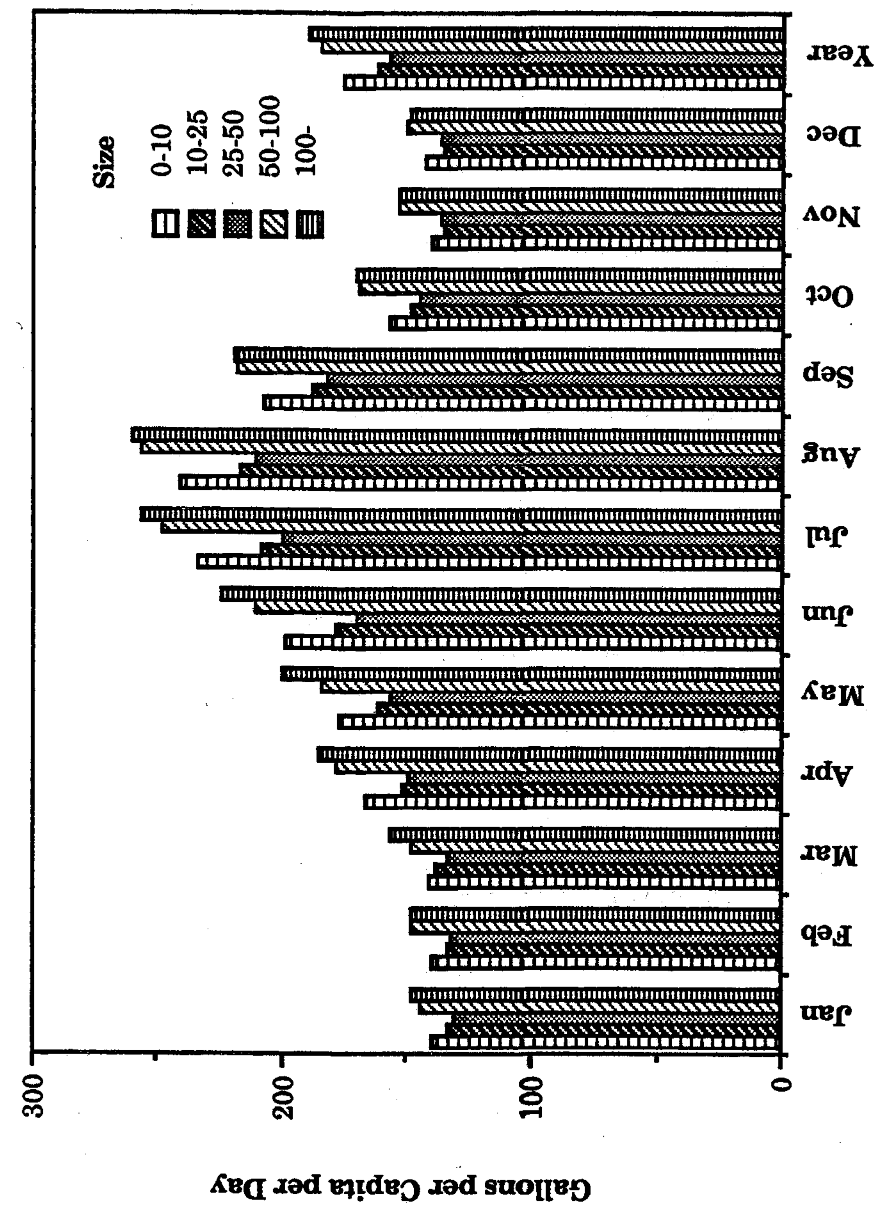

Figure 2. Monthly and Annual Water Use by Size

To further characterize the monthly patterns of water consumption by size, the following procedure is adopted. Monthly means are computed for consumption in each community across the five years. In each size classification minimum and maximum levels of these means and their differences are graphed in Figure 3. First, the difference between minimum and maximum is well below one hundred gallons per day for all five sizes of population. This result implies that, for every month during the study period, there has not been grossly varying consumption behavior across different community sizes. Second, winter consumption is consistent through all sizes. Third, in contrast to winter consumption, May through September consumption possesses bigger differences between minimum and maximum than those of winter consumption. However, July consumption in the smaller communities (size A and B) is noticeably consistent compared to the rest of the summer.

Water Use by Region

To compare water consumption by region, the regional definitions employed in the Texas Water Plan are adopted. A map of Texas showing these eight regions is exhibited in Figure 4.

The number of communities in each region is depicted in Figure 5. It is evident that our sample is not well balanced in terms of the number of communities in region 1. The low population density of region 1, however, limits the number of communities in the sample. Information for this region is dominated by El Paso because of population weighting.

Monthly and annual water use by the eight regions is presented in Figure 6. Because region 8 is the wettest and the most humid area in Texas, it has only slight peaking and the lowest yearly use. Regions 4 and 5 which are the next wettest regions have the next lowest yearly water use. Region 1 (the driest region) has an earlier summer peak than other regions and has low August consumption. In comparison with the rest of the regions, region 7 has unusually high consumption from late fall to late spring. Moderately dry weather and a long growing season is probably responsible. The most water use in seven months of the year (October through April) among the eight regions is recorded in region 7.

Minimum and maximum levels of individual community's monthly means and differences between these minima and maxima are graphed in Figure 7. A few different patterns of water consumption across regions are characterized. First of all, water consumption in region 1 varies little during the year for the five year study period. The only exception is shown in August consumption. This latter finding results from the small number of observations (only two communities) in the region. Second, regions 4 and 6 show similar patterns. Their summer consumption of water is widely ranged while winter consumption is fairly stable. In region 2, there is wide range of summer consumption among the communities of this region during the five year period. Region 3 not only shows a widely ranged summer consumption but also indicates a broad range of winter consumption. This region shows a difference of more than 150 gallons per

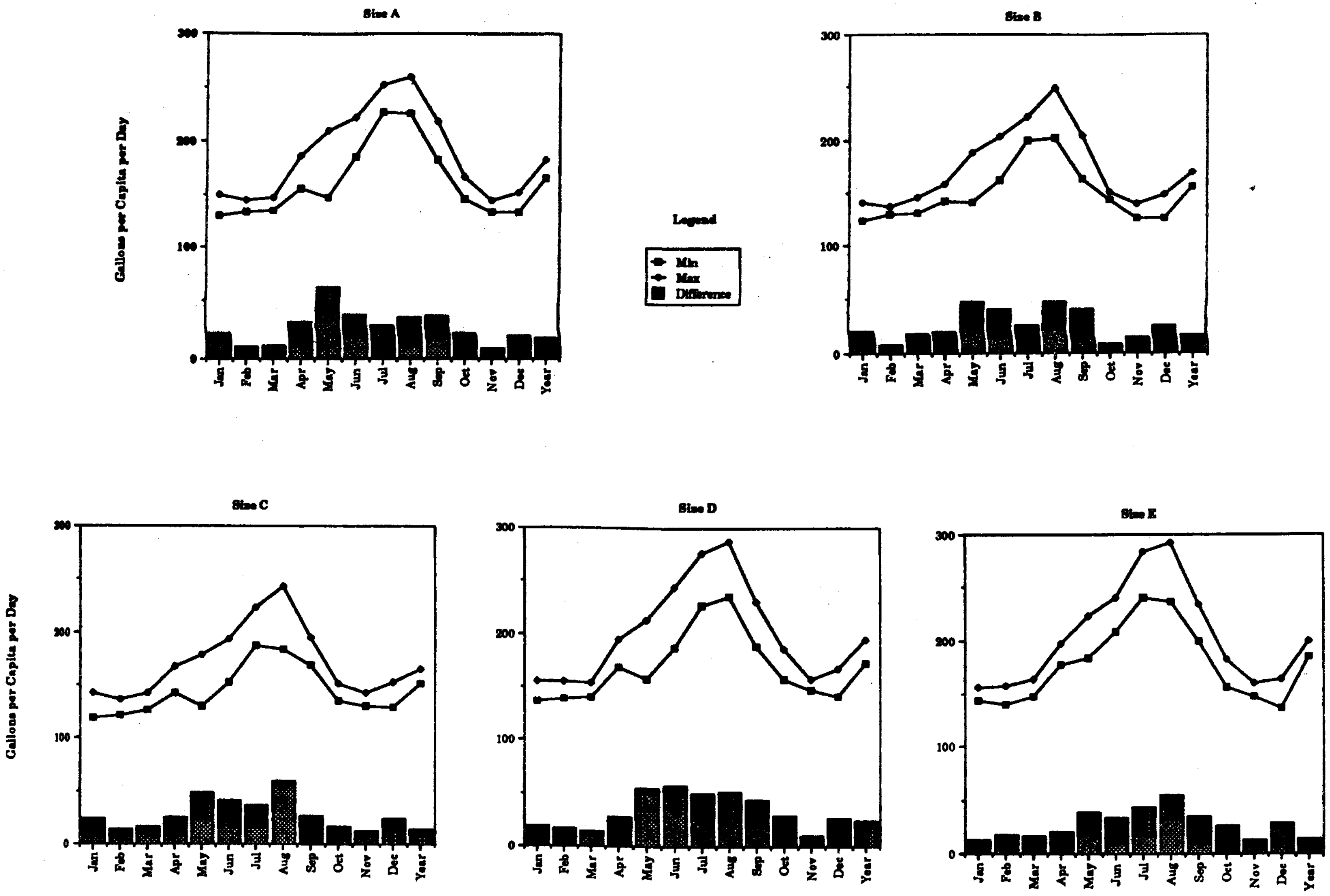

Figure 3. Monthly and Annual Water Consumption Range by Size Classification

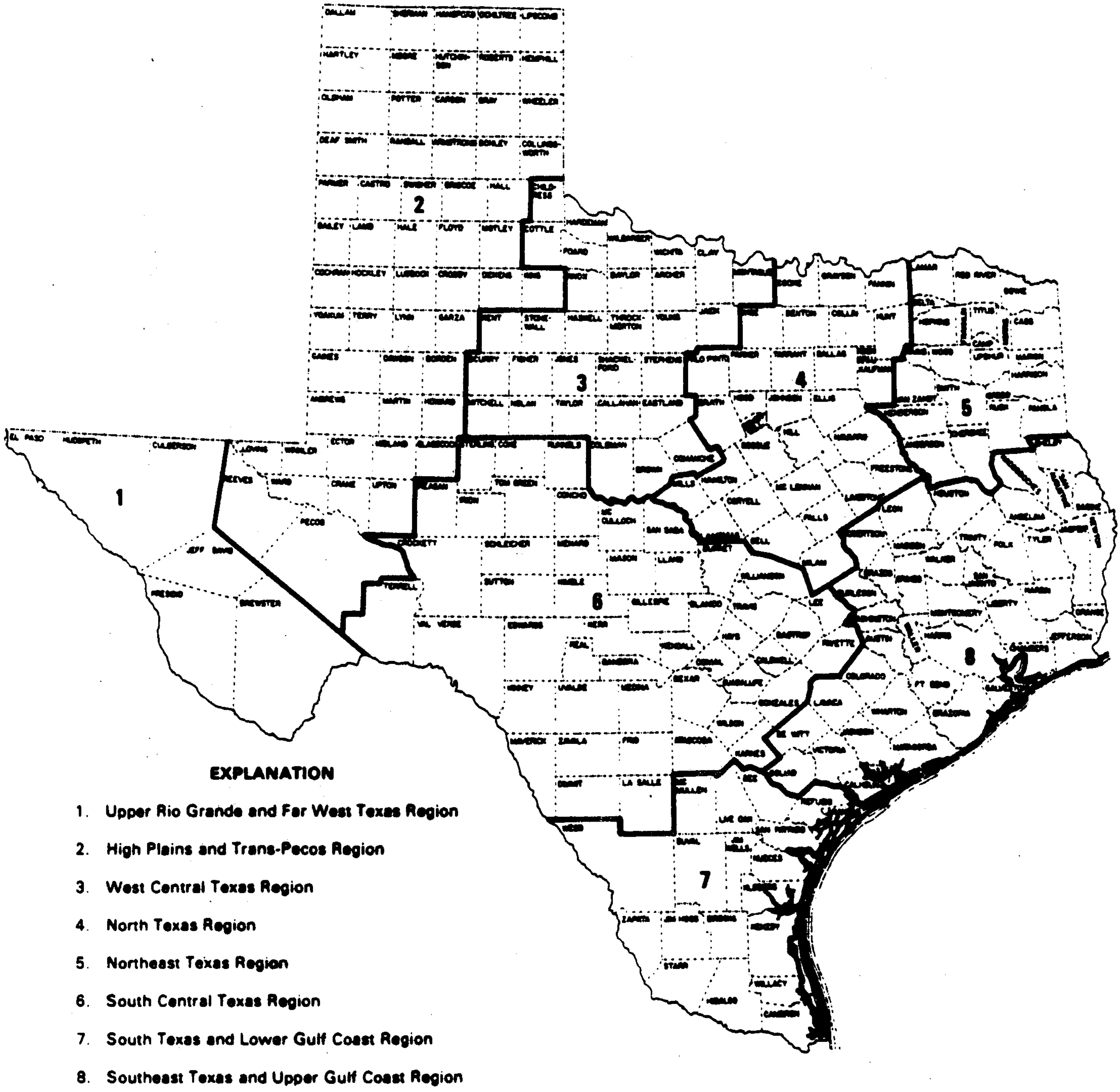

Figure 4. Major Geographical Regions in Texas
(Source: TDWR, 1984)

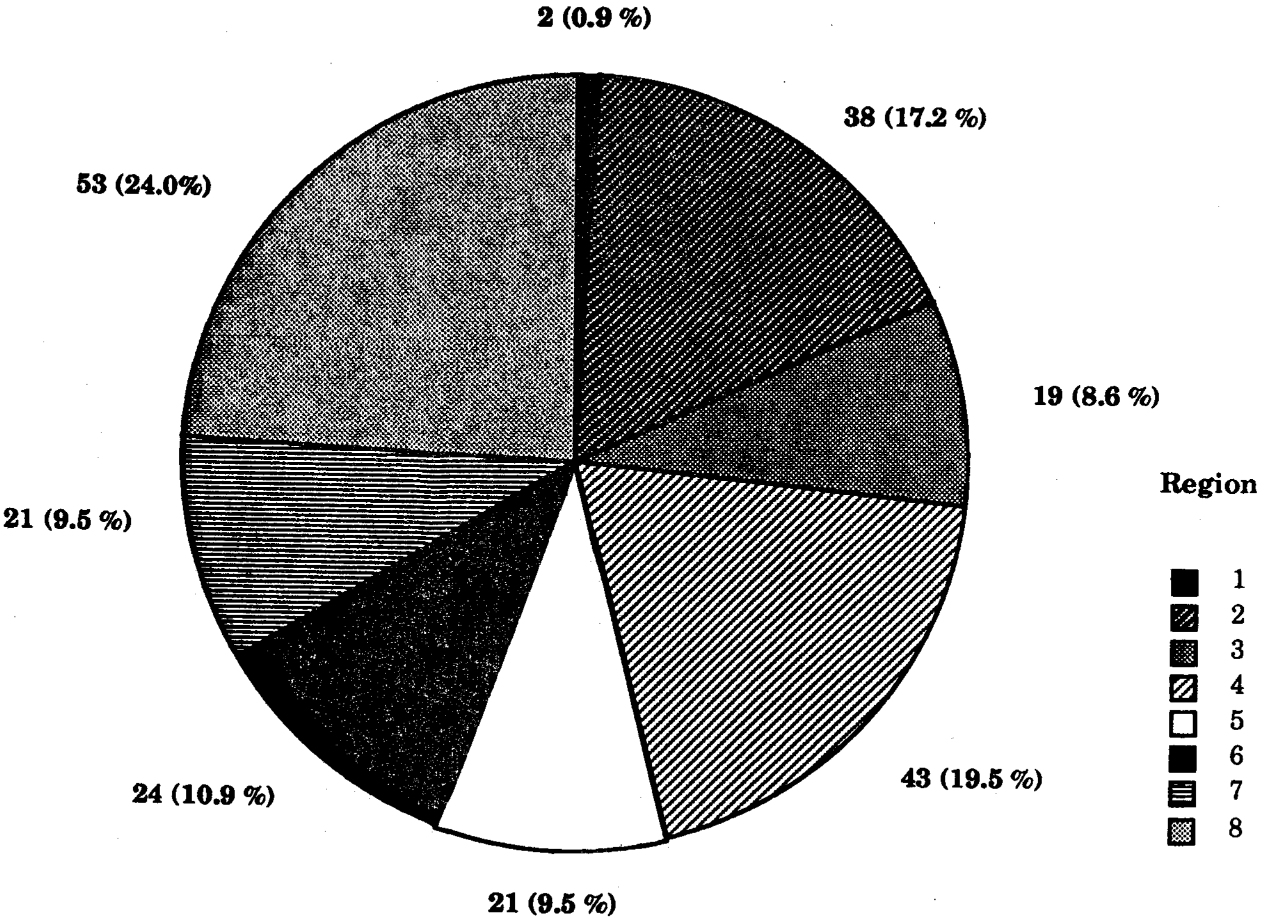

Figure 5. Number of Communities in Each Region

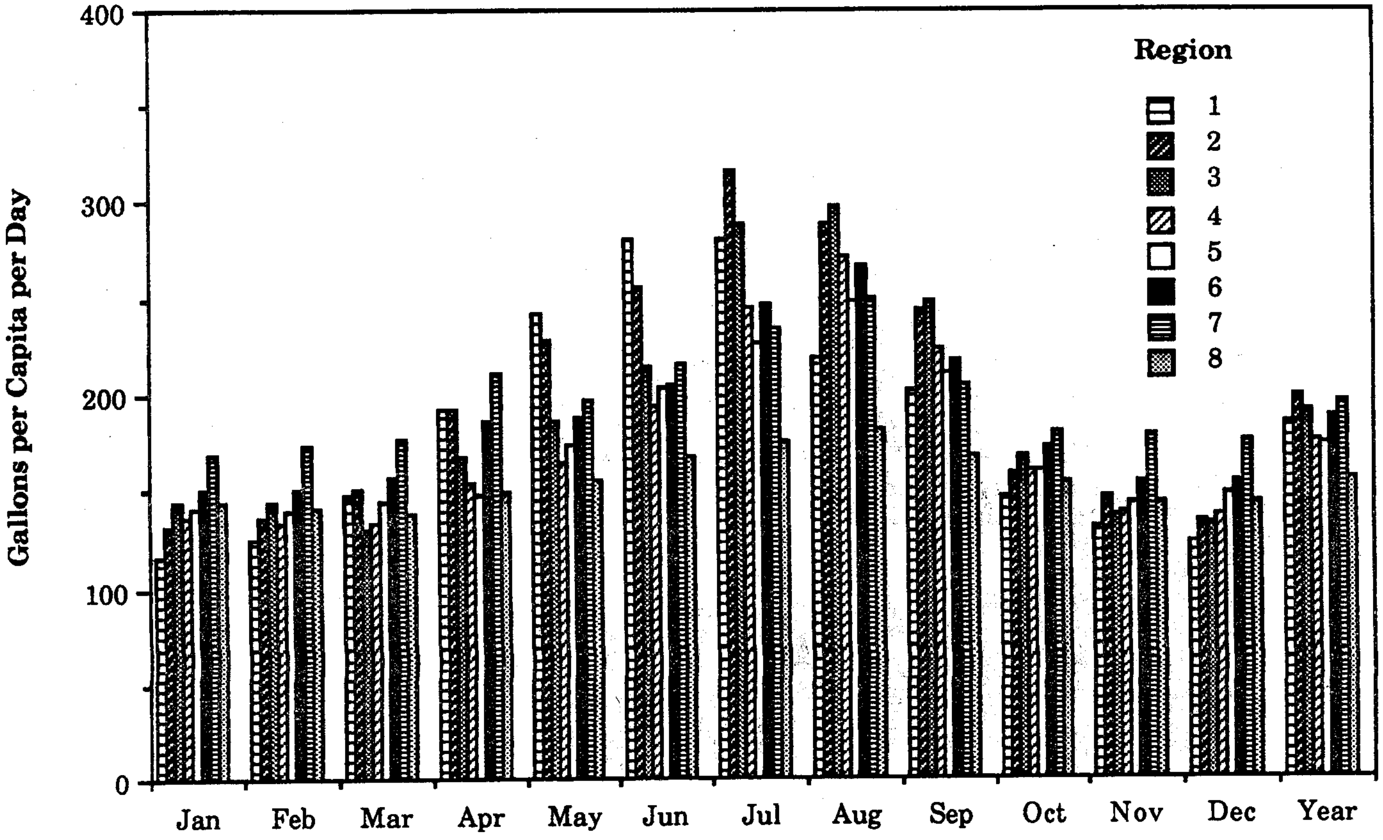

Figure 6. Monthly and Annual Water Use by Region

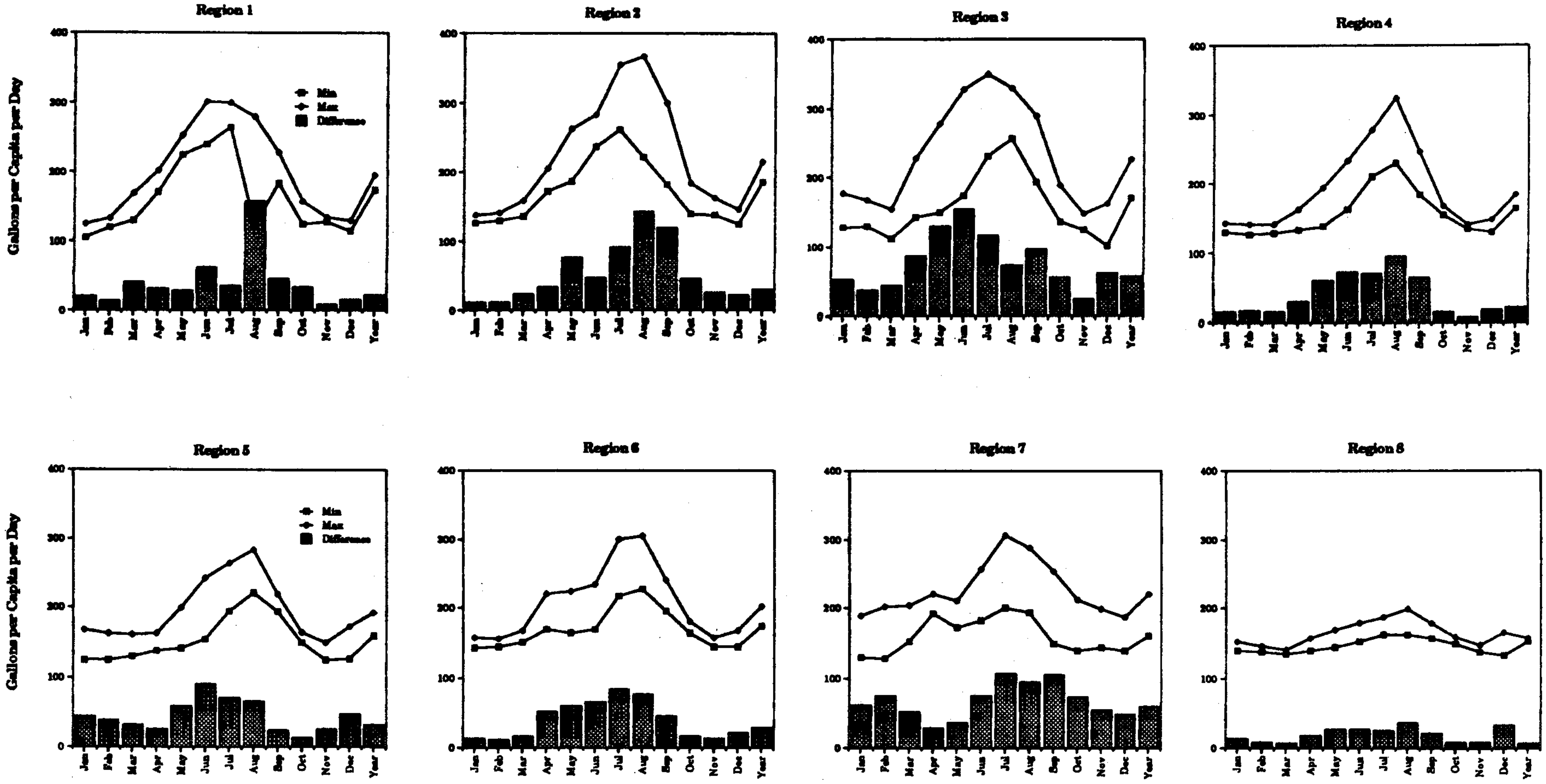

Figure 7. Monthly and Annual Water Consumption Range by Region Classification

day summer consumption among different years. Except for a few months in late spring, it is shown that different communities' water uses differ widely in region 7. Finally, region 8 is peculiar in that its water consumption is almost uniform throughout the whole year for the five year period of this study.

Water Rates

The following investigations apply only to water rates. Sewer rates are explored in a later section.

Structure

Four alternative structures are available for defining water rates: unmetered (flat rate), decreasing blocks, constant block, or increasing blocks. In an unmetered system households pay a fixed monthly fee and the water bill is independent of water consumption. In the three other rate structures each household pays a fixed monthly base rate (minimum bill) plus an amount related to metered water consumption. The base rate often entitles the user to a small amount of "free" monthly water consumption. For the simple, constant block arrangement the marginal price of water (the cost of each additional unit of water) is constant across all quantities exceeding the free water, and the month's water bill is given by

$$\text{Water Bill} = BR + P \cdot (X - F)$$

where BR is the base rate,
P is marginal price,
X is metered water consumption, and
F is the amount of free water.

Decreasing block rates utilize a multiblock system in which marginal price declines as consumption rises. Increasing block rates incorporate increasing marginal prices in a multiblock arrangement. In both cases the water bill is generically given by

$$\text{Water Bill} = \begin{cases} BR + P_1 \cdot (X - F) & \text{if} \quad X \le B_1 \\ BR + P_1 \cdot (B_1 - F) + P_2 \cdot (X - B_1) & \text{if}\, B_1 < X \le B_2 \\ \bullet & \bullet \\ \bullet & \bullet \\ \bullet & \bullet \end{cases}$$

where P_i is marginal price within block i, and
B_i is the quantity of water defining the end of block i.

$P_1 > P_2 > \ldots$ for decreasing block rates and $P_1 < P_2 < \ldots$ for increasing block rates. Because of the "cost of service" approach used by many utilities in determining block rates, decreasing block rates were historically popular (American Water Works Association 1983). As a means of inducing conservation, however, the use of decreasing blocks has been falling in the United States.

For the study period each community's rates are examined twice a year (June and December) to assess rate structure. Because it is possible for a multiblock structure to take on a decreasing block character across one range of consumption levels and an increasing block character across another, this examination identifies marginal water price at 30,000 gallons and compares this marginal price to the marginal price for the preceeding block (if one exists). The number of communities using each structure type is counted, and the results appear in Figure 8.

Numbers of increasing block rates and unmetered rates are only slightly changing during 1981-85. By December 1984, there were no systems using unmetered rates. As suggested by Figure 8, constant water rates are steadily replacing decreasing block rates during most of the study period. A constant block structure is the most popular arrangement among the 221 communities followed by decreasing block rates and increasing block rates.

Marginal Water Price

To illustrate water rates, June and December marginal prices faced by the average household are computed at 500 gallon intervals beginning at 250 gallons. Averaging prices in these two months produced the schedules of marginal water prices shown in Figure 9[2]. Inspection of this graphic reveals significant growth in water rates. Based on these data, annualized growth in marginal price at 30,000 gallons has averaged 11.9% per year. Precisely similar calculations show that the Consumer Price Index (given in Appendix D) increased by 4.1% per year. Therefore, the real rate of water price growth in Texas has been a sizeable 7.8% annually.

Water Bills

Monthly and annual household water bill as well as the marginal water prices are computed for each community at each month's water consumption level. These water bills are analyzed by three categories--year, size, and region--as was discussed in the water consumption section.

Trends of the monthly and annual water bill by each study year are shown in Figure 10. It is clear from this figure that household water winter bills for each community go up each year with the exception of December 1984. December 1983 and January 1984 were months of exceptionally high bills because low temperatures caused broken pipes in parts of Texas.

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[2] Average monthly water bills can be obtained by integrating under the appropriate schedules of Figure 9 and adding the result to the appropriate average base rate (given parenthetically for each year in the figure).

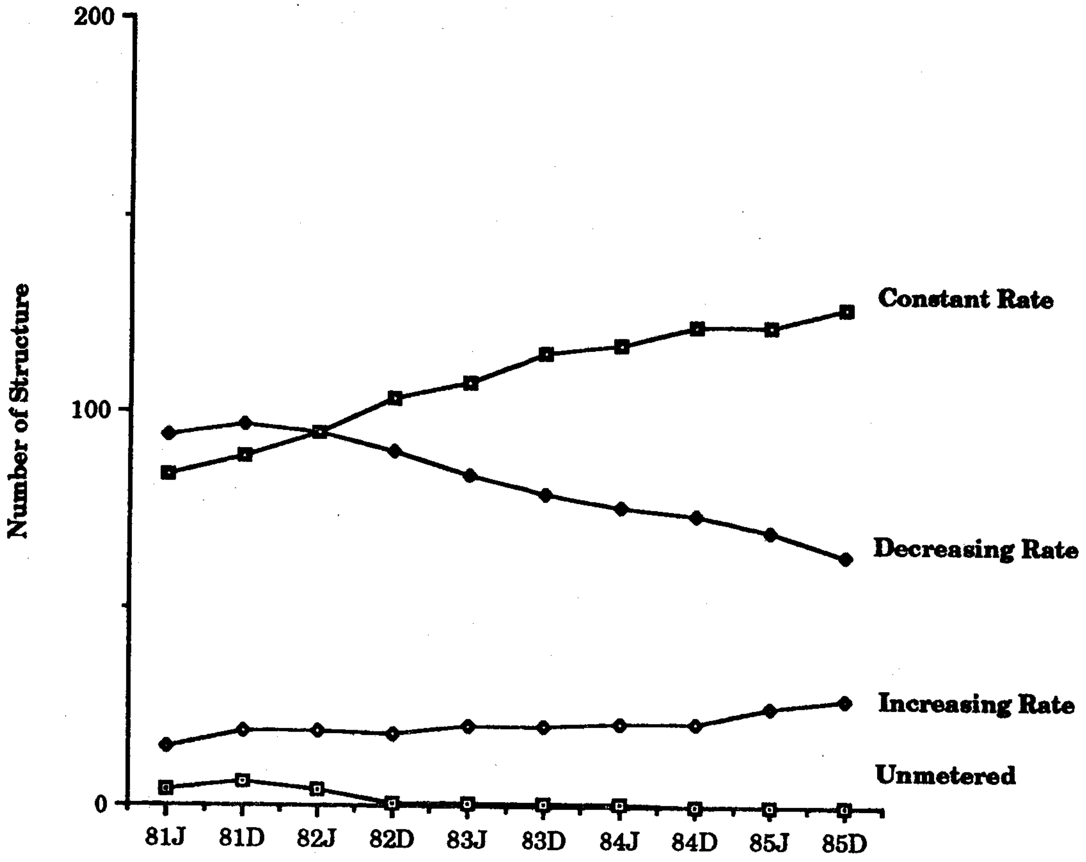

Figure 8. Water Rate Structure

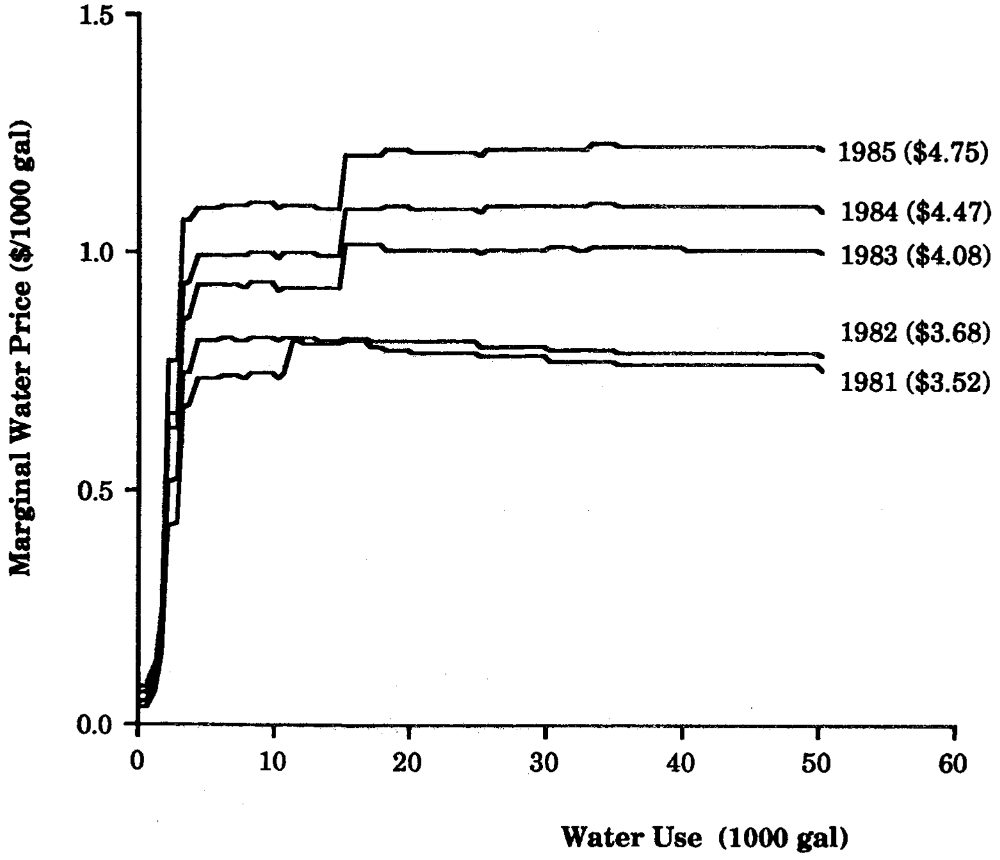

Figure 9. Marginal Water Prices by Year

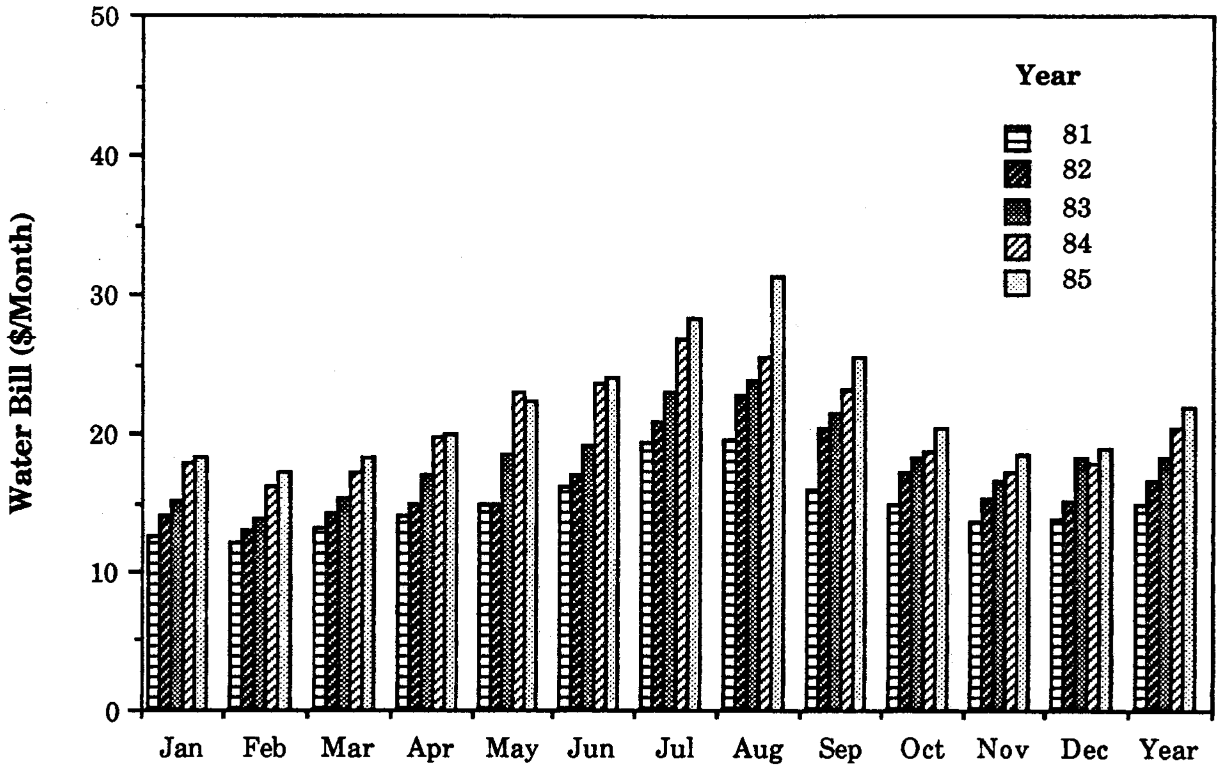

Figure 10. Monthly and Annual Water Bill by Year

As in the water consumption analysis, five groups of population sizes are used to analyze the water bill by different size in Figure 11. It is noteworthy that population size does not appear to affect the water bill for the study period.

Monthly and annual water bills for the eight different regions are shown in Figure 12. High bills for summer and low bills for winter are clearly seen for every region. Water bills for region 3 are the highest among all regions most months. Water bills for region 8 are almost stable across the different months.

Sewer Rates

Structure

Numbers of decreasing block, increasing block, constant, and unmetered structures are shown in Figure 13. During the study period, the numbers of increasing block rates and decreasing block rates stayed almost constant. Unmetered sewer rates are being replaced by constant rates. It is also clear that constant sewer rates have become the most popular structure in Texas communities.

Marginal Sewer Price

Averaging marginal sewer prices faced by the average household in June and December produced the schedules of marginal sewer prices shown in Figure 14. Some communities define a maximum sewer bill which causes the marginal monthly sewer price schedules of Figure 14 to begin declining after a certain point. Annualized growth in marginal sewer price at 30,000 gallons has been 16.0% per year[3]. The real rate of sewer price growth was 11.9% annually.

Sewer Bills

The monthly and annual sewer bill are presented by year in Figure 15. It is evident that bills go up by year in every month and every year. The difference, however, between the highest and the lowest is less than $5 per month.

As shown in Figure 16, sewer bills are dissimilar by size. Households in large communities generally pay higher sewer bills. Size D (50,000 - 100,000 population), in particular, pays the highest sewer bills among the five different groups of population. During the study period, small communities (size A) paid the lowest sewer bills.

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[3] Combining nominal marginal water and sewer prices indicated that the true cost of water to the consumer increased 12.95% annually during this period.

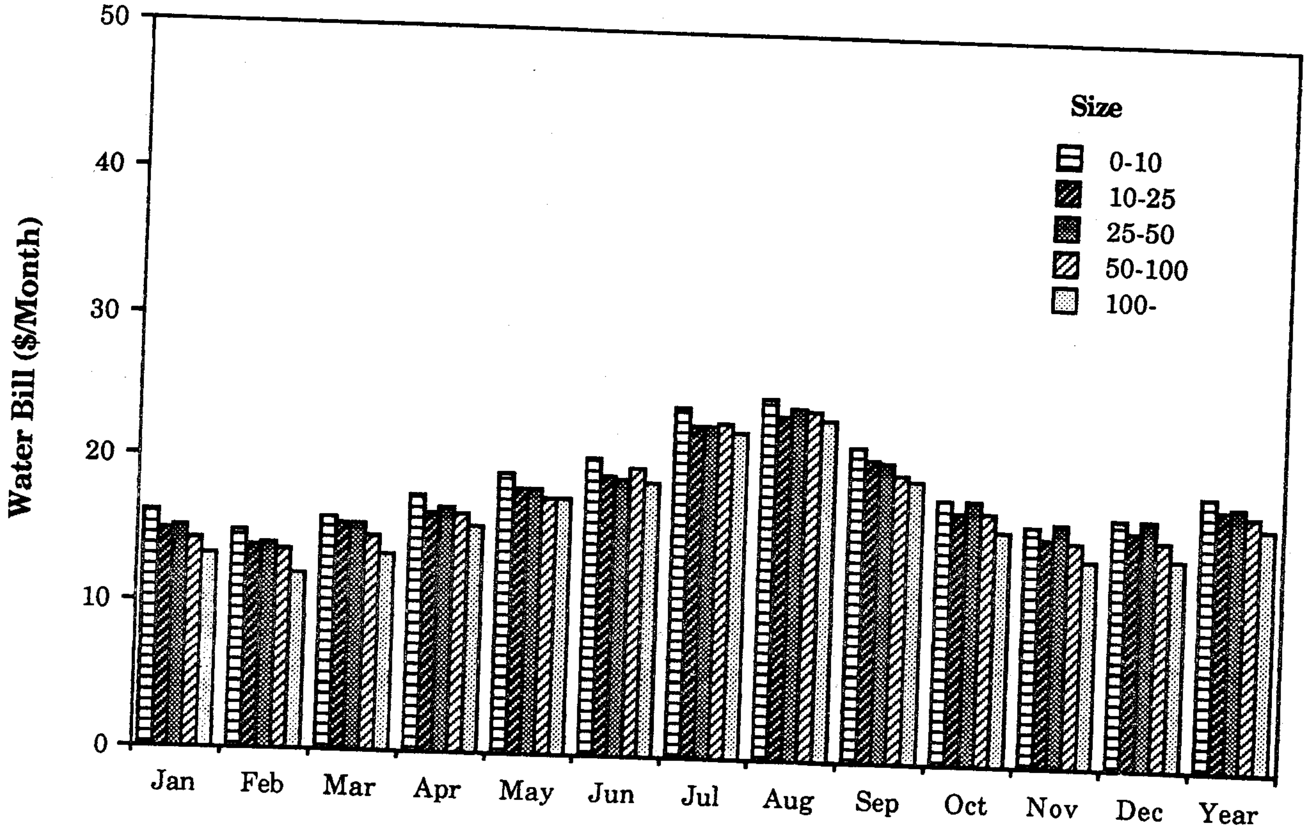

Figure 11. Monthly and Annual Water Bill for Each Size

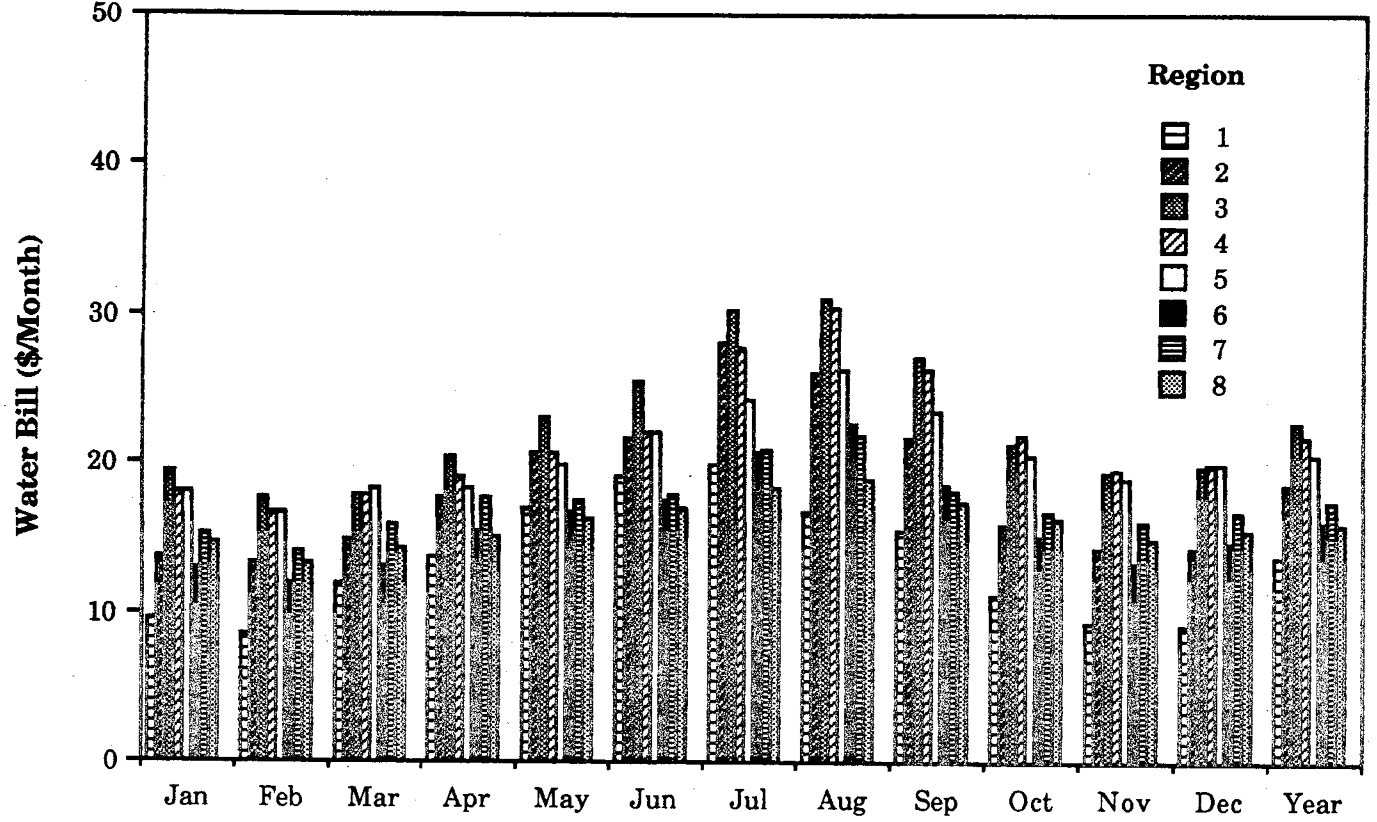

Figure 12. Monthly and Annual Water Bill for Each Region

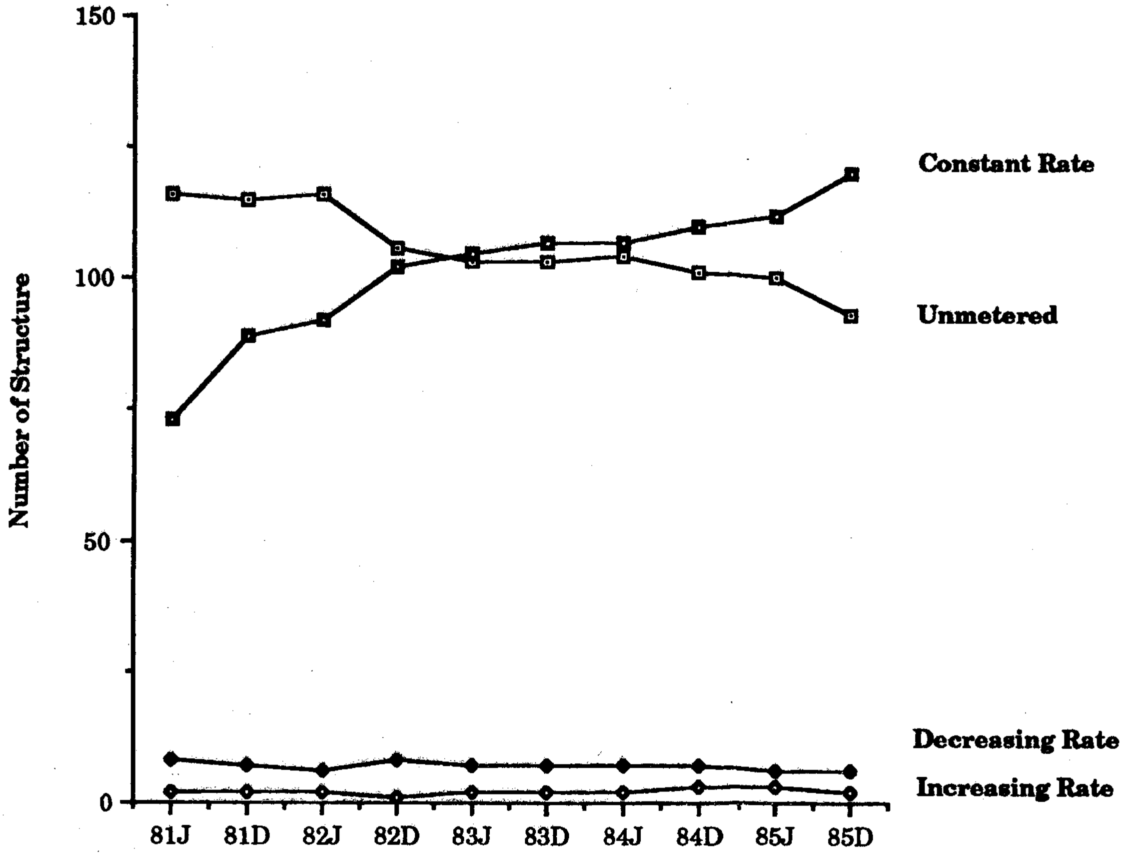

Figure 13. Sewer Rate Structure

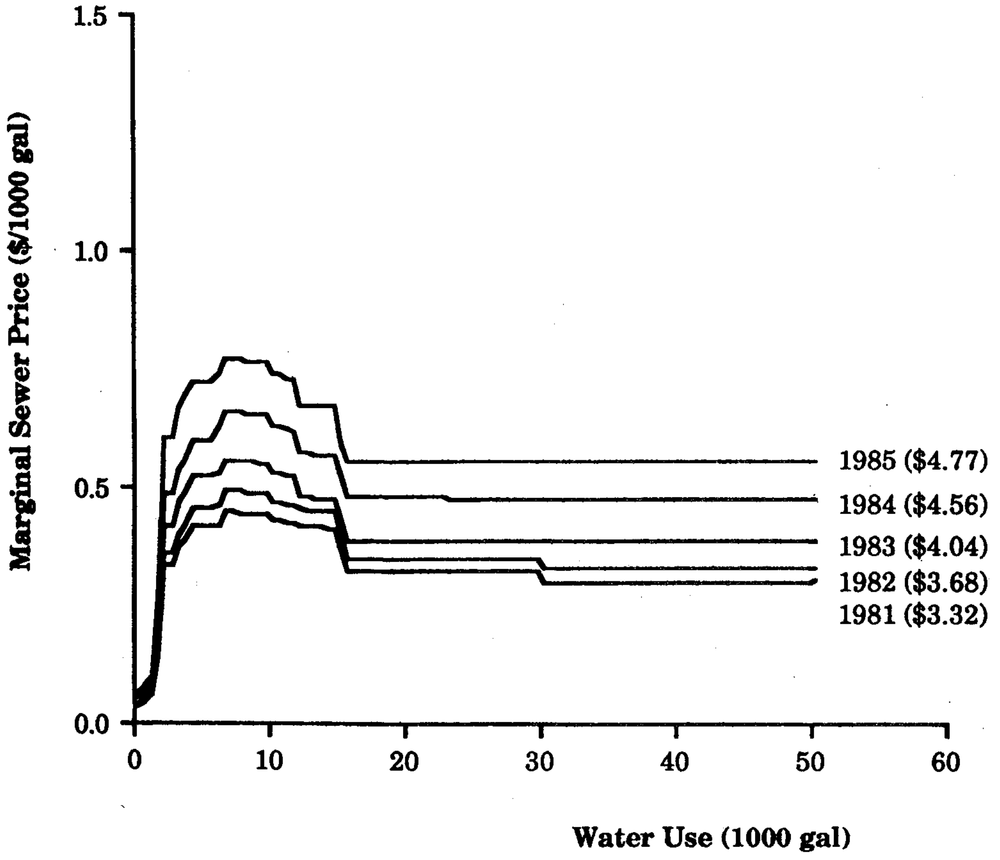

Figure 14. Marginal Sewer Prices by Year

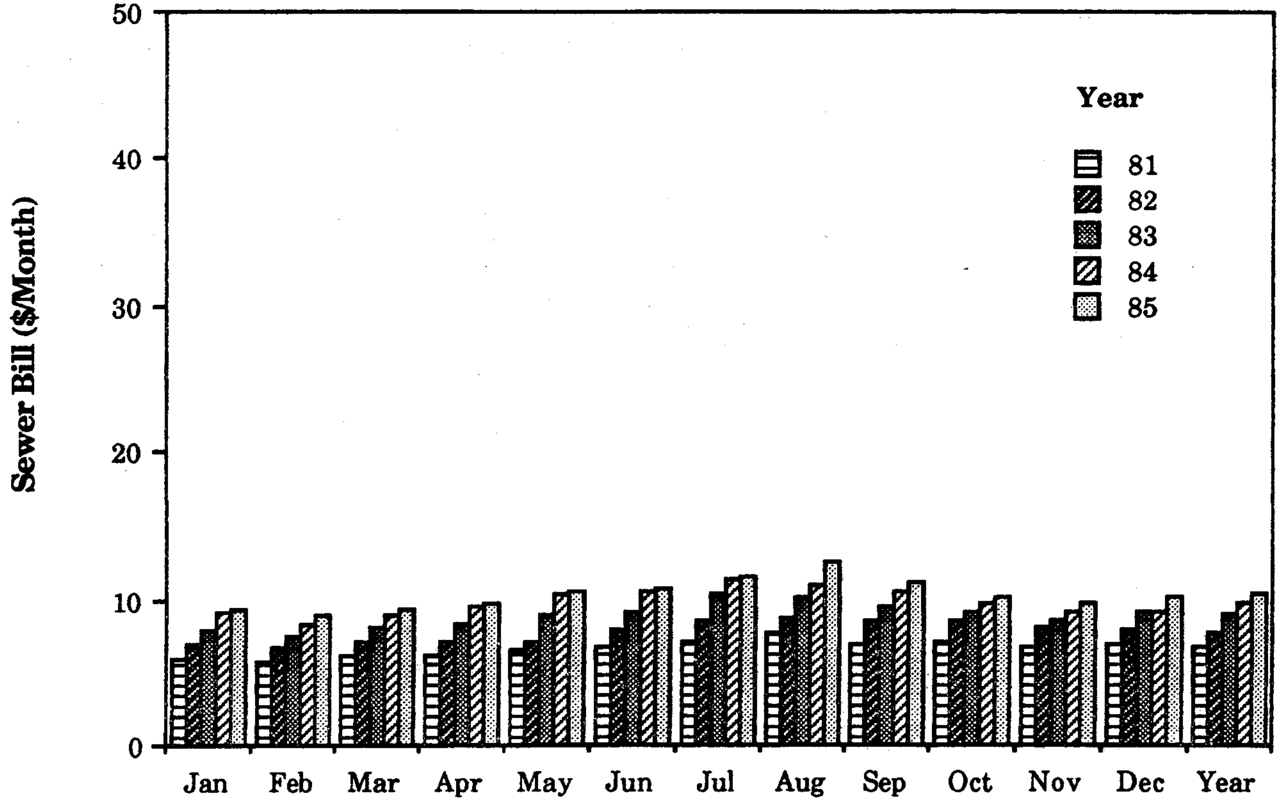

Figure 15. Monthly and Annual Sewer Bill by Year

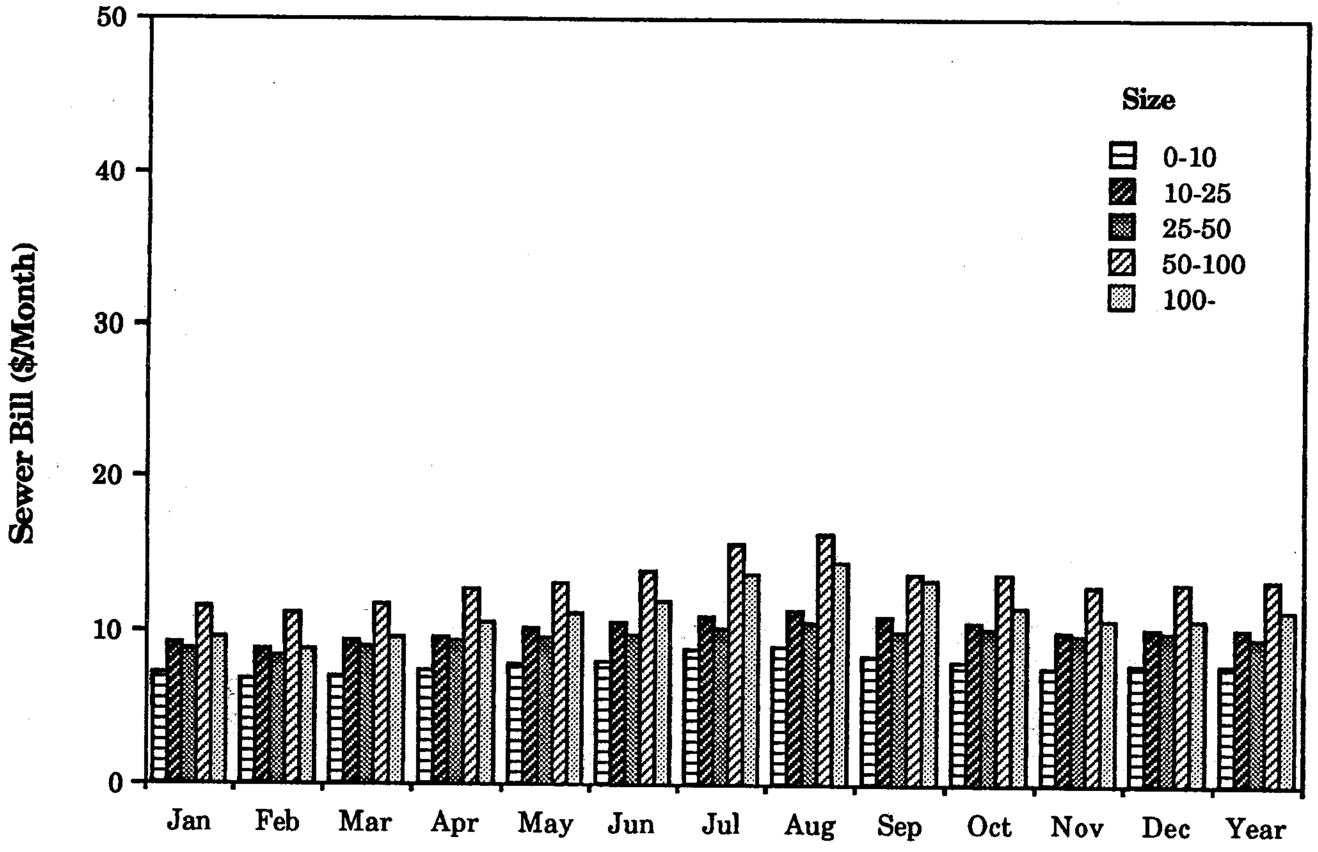

Figure 16. Monthly and Annual Sewer Bill for Each Size

It is shown from Figure 17 that all regions but 3, 4, and 6 had relatively unvarying sewer bills over the year. Region 8 paid the highest sewer bill during the study period, while communities in regions 1 and 2 paid about 40% of the amount for sewer bills paid by a community in region 8. The summer sewer bill in region 3 is notably high.

IV. COMMUNITY WATER DEMAND IN TEXAS

Pretesting

The first stage of econometric analysis used only a small subset of the 12,050-observation dataset. These pretest findings have been reported by Griffin and Chang (1988). Necessary elements and results of the pretest work are repeated without attribution here. The earlier analyses included an original supply model but highlighted a linear demand model. Based upon these results the following general linear model is proposed.

$$Q = \alpha_0 + \alpha_1 AP + \alpha_2 APxC + \alpha_3 I + \alpha_4 SP + \alpha_5 C + \alpha_6 AAP + \mu \qquad (A1)$$

where Q is per capita residential and commercial water consumption (gallons per day);

AP is the average price of water paid by an average household (dollars per thousand gallons);

C is the number of days without a significant rainfall (≥ 0.25 inches) times the month's average temperature (degrees Fahrenheit);

I is annual personal income per capita (thousands of dollars);

SP is percent of the population with Spanish origin; and

AAP is average annual precipitation during 1951-1980 (inches).

Q, AP, and I are commonly employed in similar studies and therefore require no explanation. A sociology study using Texas data found that SP had a statistically significant negative relationship with water consumption (Murdock et al.). Pretest results did not confirm this result, but collinearity between SP and unspecified climatic/geographic variables prohibited any conclusions. A long term climate variable, AAP, is incorporated into the present model for the purpose of reexamining the influence of Hispanic ethnicity. While the climate measure, C, has not been used previously (except by Griffin and Chang), it seems to offer highly desirable conceptual properties. C is sensitive to (1) summer lawn watering behavior which usually postpones irrigation when a rainfall occurs, (2) winter behavior in which irrigation is minimal, and (3) the varying number of days in different months.

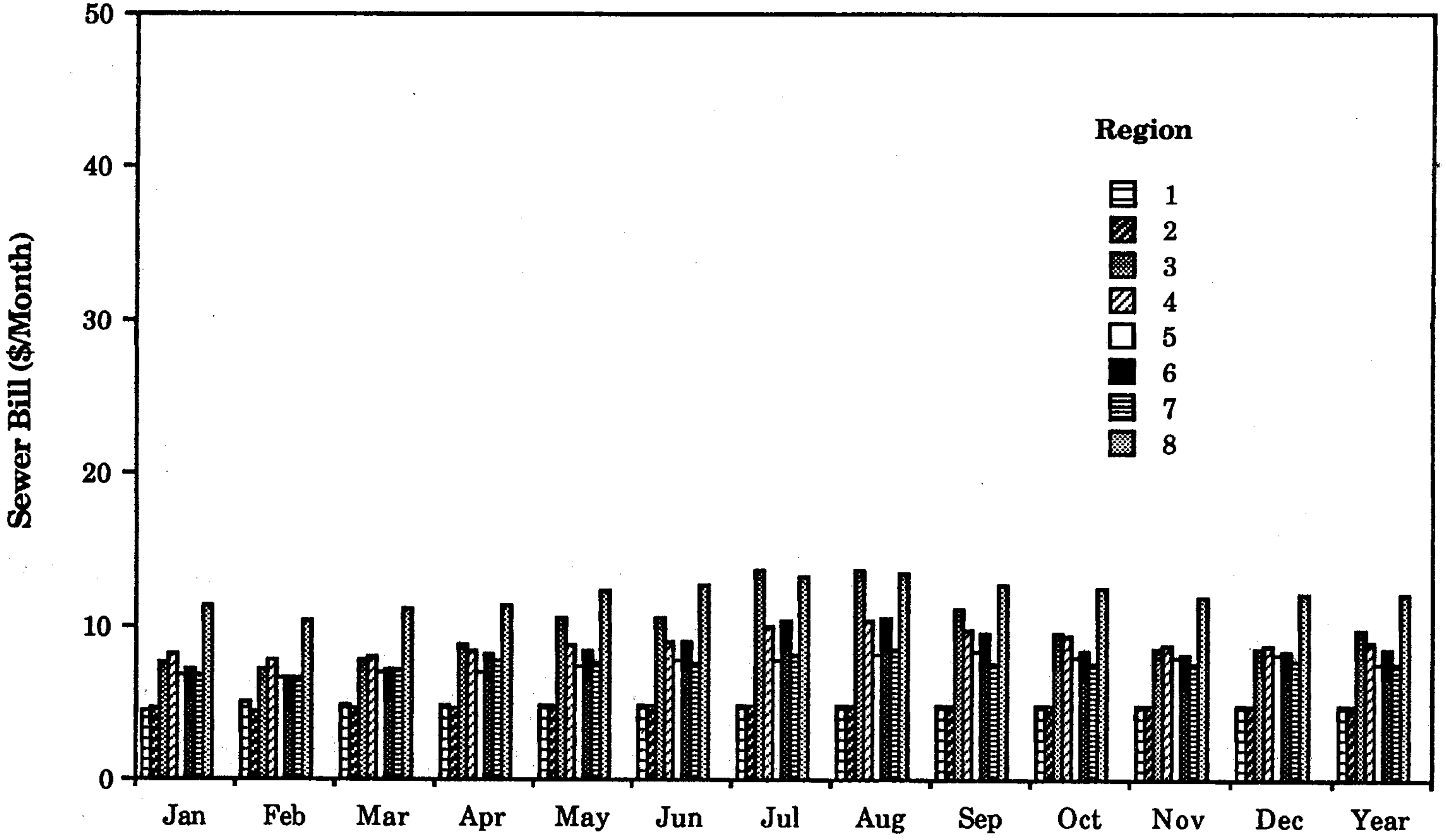

Figure 17. Monthly and Annual Sewer Bill for Each Region

Linear Models

Several models are reported in the remainder of this section. Particular uses of specialized models are given as necessary. Guidance for selecting among the alternative models is presented primarily in the Conclusions. Four predominately linear models (A1-A4) are estimated. The main "linear" model (A1) is a pure linear model using the average price specification plus an APxC term. The second linear model (A2) is the pure linear model (omitting the APxC cross product from model A1). The third and fourth "linear" models (A3 and A4) add terms to the main model which are necessary to perform marginal price and sewer-price-excludability tests. Models A1 or A2 are most appropriate for further applications as A3 and A4 are intended only for hypothesis testing.

These four models are each estimated using the complete 221-community, five-year sample. As discussed in section II, there are 12,050 observations in this dataset. For the interested reader simple correlations among the several exogeneous variables are available in Appendix C. Minima, means, maxima, and standard deviations for individual variables are also provided in Appendix C because certain applications benefit from this information.

Table 2 contains parameter estimates for all four linear models. *F* and *t* statistics are generally large for models A1-A4 due to the large number of observations. The monthly climate variable offers the most statistically significant parameters, and the similarity between the C parameter estimate of model A2 and that of the original pretest model (Griffin and Chang) is remarkable. Looking across these four alternative specifications, it is notable that parameter estimates for I, SP, C, and AAP are very stable. The same is not true for the several price variables because price terms are being excluded/included alternately.

The main model (A1) offers only a slightly improved fit over the pure linear model (A2) but appears better able to identify time-variant price elasticities. Across the dataset an individual in the average community consumes 169 gallons per day at an average price of $1.98 per thousand gallons (Table C-3). Employing A1 estimators,

- a 10¢ increase in AP decreases water demand by 2.24 g/c/d (at the average level of C);
- a $1000 rise in income raises demand by 4.2 g/c/d;
- each percentage point of Spanish population lowers demand by 1.17 g/c/d;
- a 100 unit increase in C increases demand by 7.68 g/c/d (at the mean AP); and
- a one inch increase in average annual precipitation decreases demand by 1.39 g/c/d.

Table 2. Parameter Estimates for the Predominately Linear Models*

Q =	A1	A2	A3	A4
Intercept	11.66 (1.88)	100.83 (26.28)	6.02 (0.99)	17.77 (2.62)
AP	22.23 (8.88)	-21.81 (-35.83)	22.53 (8.41)	19.12 (4.57)
APxC	-0.0248 (-18.09)		-0.0205 (-14.19)	-0.0256 (-11.26)
PO			-31.82 (-5.52)	
POxC			0.0417 (12.93)	
-APS				6.27 (0.94)
-APSxC				0.0018 (0.50)
I	4.21 (13.25)	4.09 (12.72)	3.69 (12.09)	4.03 (12.66)
SP	-1.17 (-12.75)	-1.17 (-12.59)	-1.12 (-12.76)	-1.25 (-13.47)
C	0.126 (42.93)	0.077 (65.13)	0.134 (46.59)	0.126 (39.12)
AAP	-1.39 (-26.75)	-1.42 (-27.00)	-1.35 (-26.96)	-1.47 (-27.46)
F	1283.1	1435.4	1182.9	969.7
R^2	0.39	0.37	0.44	0.39
n	12050	12050	12050	12050

**t* statistics in parentheses

Hypothesis tests involving parameter estimates for AP and PO in model A3 can be used to obtain empirical evidence regarding whether consumers respond to marginal or average prices. PO = MP - AP where MP is the marginal price of water to the average household, and AP is as previously defined. If $\alpha_1 = \alpha_3$ and $\alpha_2 = \alpha_4$, then consumers are responding to marginal price instead of average price. The *F* statistic for $\alpha_1 = \alpha_3$ and $\alpha_2 = \alpha_4$ is 1155, so the hypothesis is rejected, thereby reaffirming the choice of AP over MP. Therefore, it is appropriate to employ the AP specification as all other models presented here do.

The AP and MP variables include both water and sewer prices (AP = APW + APS; MP = MPW + MPS). Most studies omit sewer prices. Such an omission is potentially negligent because sewer bills commonly depend upon water consumption. Unfortunately, there is greater variety in sewer rate structures, and they are therefore more difficult to handle in terms of computer storage/retrieval of rate data. These complexities are discussed by Griffin and Chang.

Model A4 is included to test the legitimacy of excluding sewer rates. If APS can be neglected, then $\alpha_1 = \alpha_3$ and $\alpha_2 = \alpha_4$. The *F* statistic for this hypothesis is 125.8 so it is rejected with over 99.9% confidence. This clearly suggests that analyses which fail to incorporate sewer prices are deficient in the sense that an important explanatory variable is excluded. Moreover, APW and APS are positively correlated, so the exclusion of APS probably biases the regressor of APW negatively (APW elasticity is overstated). The statistical importance of sewer prices is interesting in that the majority of consumers are probably unaware that their water consumption influences their sewer bill. This is additional evidence, along with the superior performance of the AP specification, that what consumers really respond to is their utility bills.

Logarithmic Models

The above analyses were conducted with predominately linear forms. Literature in this area offers linear and double log (Cobb-Douglas) demand estimates almost exclusively. Ease of use and the use of linear models in previous water demand research are the two main attributes offerred by the linear form. The imposition of an intercept along the price axis and poor predictive ability outside of the data range are the main disadvantages of the linear form. The restrictiveness of this form is well known in other literature areas (Griffin, Montgomery, and Rister 1987). The double log form is popular in demand estimation because price elasticity immediately emerges as an parameter estimate.

To permit comparisons with preceeding research, it is important to estimate linear and double log models. The convenience of these two forms can be overestimated, however, for the use of monthly data in pretest work indicated the presence of a time-varying price elasticity (Griffin and

Chang). Adequate incorporation of this finding required, minimally, that the linear form be augmented with price-climate crossproducts. The double log form may require a similar augmentation, as it identifies a single price elasticity when applied strictly.

Estimating the double log form provides a rectangular hyperbola which is asymptotic to both axes in the quantity-price plane. It is probably appropriate for a water demand function to be asymptotic to the price axis, because the necessity of water for life implies that there is no price which could bring demand to zero. Maintaining a demand curve which is asymptotic to the quantity axis, however, implies that there is no possibility of satiation. This later problem can be solved by modifying the double log form to[4]

$$\ln Q = \delta_0 + \delta_1 AP + \delta_2 \ln I + \delta_3 SP + \delta_4 \ln C + \delta_5 \ln AAP.$$

This type of specification has been used by Foster and Beattie (1979). It is asymptotic to the price axis, has a positive quantity axis intercept, and is <u>not</u> a constant elasticity relationship. A somewhat more exotic method of obtaining the same features is to employ the Generalized Cobb-Douglas form:

$$\ln Q = \delta_0 + \sum_i \sum_j \delta_{ij} (\ln (x_i + x_j))/2$$

where $\delta_{ij} = \delta_{ji}$ for all i, j and x_i, x_j = AP, I, SP, C, or AAP. The greater number of parameters (16) in this model can make application more difficult, but results may be interesting. Our perusal of other popular functional forms did not identify alternatives offerring sufficiently better properties.

Four models (B1-B4) involving various logarithmic transformations are estimated. The dependent variable is ln Q for all four of these models. The main log model (B1) is the pure double log (Cobb-Douglas) form. The second model (B2) employs AP rather than ln AP as the price term. The third model (B3) incorporates both AP and ln AP as explanatory variables. The fourth model (B4) is the Generalized Cobb-Douglas functional form.

Parameter estimates for the first three logarithmic models are given by Table 3. The Generalized Cobb-Douglas model is separately presented in Table 4. The first three logarithmic models (Table 3) offer similar measures of overall fit as do the linear models. As discovered for the linear models, parameter estimates for I, SP, C, and AAP variables are very stable across models B1-B3. The primary, pure double log model (B1) may warrant a slight preference among the log models on the basis of overall fit and parameter parsimony. Model B1 indicates a constant AP elasticity of -0.32 and an income elasticity +0.13. While this price elasticity is in the range of pretest results reported by Griffin and Chang, income elasticity is now lower. The latter finding probably results from the introduction of

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[4] SP sometimes takes on a zero value in the data, so ln SP cannot be employed in a regression equation.

Table 3. Parameter Estimates for the Logarithmic Models*

ln Q =	B1	B2	B3
Intercept	0.664 (7.55)	0.729 (8.11)	0.574 (6.50)
ln AP	-0.317 (-47.01)		-0.499 (-23.37)
AP		-0.136 (-41.03)	0.0928 (9.00)
ln I	0.126 (10.76)	0.109 (9.16)	0.134 (11.48)
SP	-0.00661 (-13.01)	-0.00694 (-13.37)	-0.00622 (-12.23)
ln C	0.664 (60.86)	0.682 (61.56)	0.660 (60.60)
ln AAP	-0.164 (-19.57)	-0.190 (-22.51)	-0.155 (-18.42)
F	1523.5	1378.25	1291.54
R^2	0.39	0.36	0.39
n	12050	12050	12050

*t statistics in parentheses

Table 4. Parameter Estimates for the Generalized Cobb-Douglas Form

ln Q =	Estimator	*t*
Intercept	-5.29	-17.94
ln AP	-0.515	-20.26
ln (AP + I)	0.257	1.97
ln (AP + SP)	0.119	7.21
ln (AP + C)	109.32	6.75
ln (AP + AAP)	-0.486	-1.55
ln I	0.0425	0.42
ln (I + SP)	-0.341	-7.86
ln (I + C)	74.71	9.32
ln (I + AAP)	-0.902	-4.75
SP	0.00976	3.28
ln (SP + C)	19.35	6.56
ln (SP + AAP)	-0.568	-9.30
ln C	-235.03	-13.63
ln (C + AAP)	33.44	19.46
ln AAP	0.937	3.04
F	600.0	
R^2	0.43	
n	12050	12050

AAP — which demystifies the SP parameter and thereby lowers the I parameter estimate (SP and I are negatively correlated, Table C-1).

The several additional parameters of the Generalized Cobb-Douglas model (Table 4) improve explanatory power somewhat, and most parameters are statistically significant. The small enhancement in fit and the increase in complexity limit certain applications, but monthly elasticities from these and other models are computed in the next section. Some applications require only elasticities, and these applications can most reliably employ elasticity estimates from this model.

Using average Texas values for nonprice variables, any of the preceding models can be illustrated graphically in quantity-price space. To better demonstrate seasonal demand shifts, January and July versions of models A1 and B4 are graphed in Figure 18. Comparing the two examples of the linear model (A1), we see more of a pivoting in demand than a shifting. This counterintuitive result suggests the inferiority of linear modeling. Model B4 provides the demand shift that is expected when comparing winter and summer demands. According to model B4, at high price levels further price increases induce little conservation effort during January, but July consumption continues to fall.

Monthly Elasticities

Because pretest findings suggested seasonality in price elasticities, monthly price elasticities are computed and tabulated for selected models of the preceding sections. Elasticities for four models are presented in Table 5. Where necessary, the elasticities have been computed using overall means for I, SP, and AAP and monthly means for Q, AP, and C. Model A2 is omitted in favor of A1, and A3 and A4 are excluded because hypothesis testing was the only intended purpose of these models. Model B1 is omitted because it "maintains" a constant elasticity of -0.32.

The linear model, A1, indicates strong seasonal price sensitivity, but the logarithmic models are not supportive. In fact, model B2 suggests an opposite variation. Further investigation indicates, however, that this result is largely maintained (forced) by the functional form, because elasticity is functionally related to a single parameter estimate[5]. Model B3 indicates that summer elasticities are slightly higher during summer months. Again, additional investigation shows that model B3 is not robust in its ability to identify monthly elasticities[6].

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[5] It can be shown that $\epsilon = \delta_1$ AP for model B2. δ_1 is constant across months, while AP declines for months of higher water consumption. Because the δ_1 estimate is negative, elasticity declines during summer months. ϵ is independent of C for this form.

[6] $\epsilon = \delta_1 + \delta_2$AP. Elasticity is a linear function of AP and is unrelated to C.

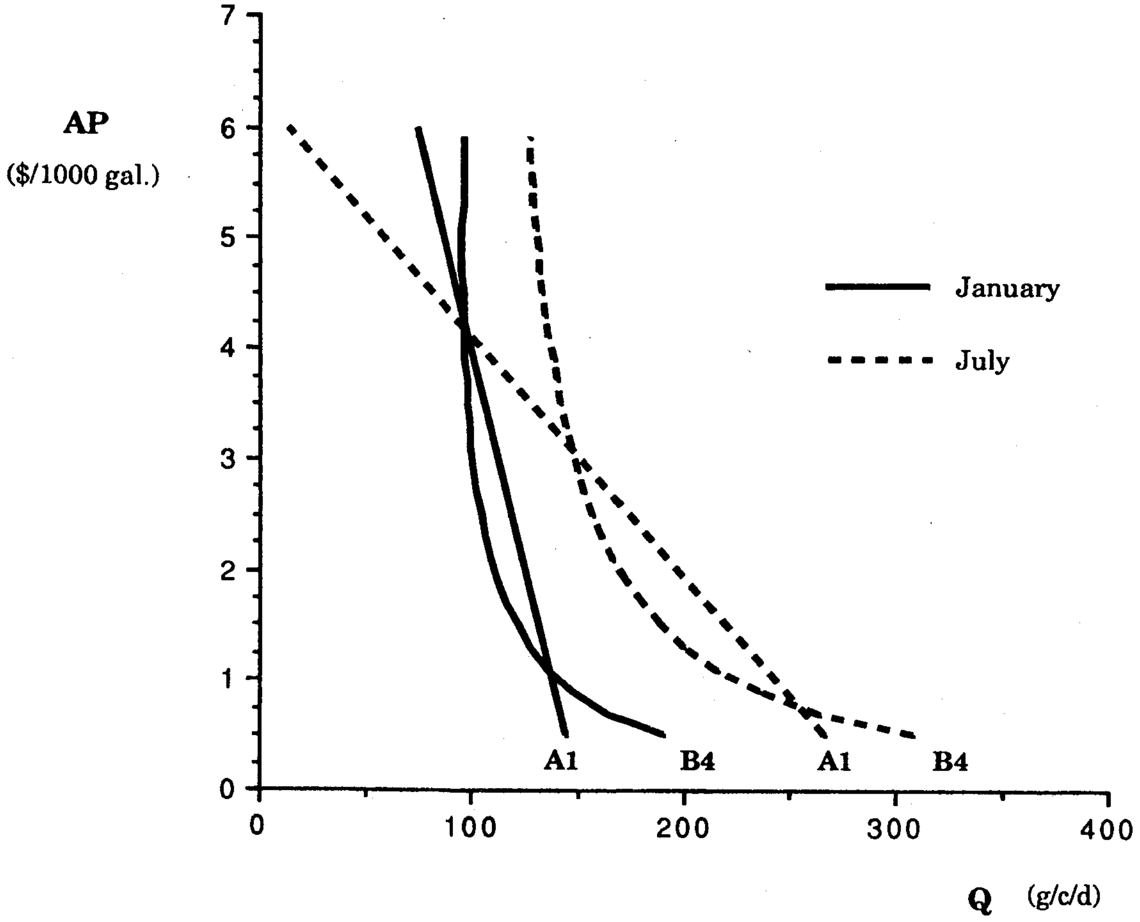

Figure 18. January and July Demand Curves

Table 5. Monthly Price Elasticities

Month	Model A1	Model B2	Model B3	Model B4
January	-.14	-.27	-.31	-.28
February	-.14	-.28	-.31	-.27
March	-.27	-.27	-.31	-.32
April	-.29	-.27	-.32	-.34
May	-.29	-.26	-.32	-.35
June	-.29	-.26	-.32	-.36
July	-.29	-.25	-.33	-.37
August	-.28	-.24	-.33	-.38
September	-.28	-.26	-.32	-.36
October	-.30	-.28	-.31	-.33
November	-.27	-.30	-.30	-.30
December	-.18	-.30	-.30	-.28
ANNUAL	-.26	-.27	-.32	-.33

The Generalized Cobb-Douglas form supports higher summer price elasticities[7] but not to the degree suggested by the linear model, A1. The higher degree of flexibility inherent in the generalized Cobb-Douglas form leads to the conclusions that this model is to be preferred and the linear model overstates seasonal elasticity variation while understating overall elasticity.

Real Prices

All of the preceding analyses have been conducted using nominal price variables. Economic theory suggests that consumers should respond to real prices. The same theory also indicates, however, that consumers respond to marginal, rather than average, price. Such theory is suspect because it fails to consider the costs of being a well informed consumer. The typical household does not know what water and sewer rates are, and these rates are not printed on their utility bills. Even if rates were known, the household may need to check the meter periodically to estimate which block (in a multiblock rate structure) will likely apply during the current billing cycle. The only readily available information is the monthly utility bill. This is undoubtedly why the AP specification is empirically preferred and why sewer price should be incorporated in AP.

If consumers are watching their month-to-month utility bills as they apparently are, then it is difficult to know whether a real price or nominal price model is better. We have pursued the nominal price approach because most applications of these results are simpler in that a normalization of prices is unnecessary.

Real price models are not without interest, however. For this reason AP, PO, and -APS are deflated using the monthly Consumer Price Index (normalized so that CPI = 100 for January 1981) available from the U.S. Department of Commerce. The index is given in Appendix D, Table D-1. The eight major models are reestimated, and results are reported in the next three tables of Appendix D. Monthly elasticities are recomputed and presented in Table D-5. The following general conclusions are apparent:

- The explanatory power of the real-price models is slightly improved over their nominal-price counterparts.
- The AP formulation is preferred (F = 1283).
- Sewer price should not be excluded (F = 164).
- Price elasticities are slightly higher. For example, the nominal price double log model (B1 in Table 3) indicates $\epsilon = -0.317$. The real price model

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[7] $\epsilon = \delta_1 + \mathrm{AP}[\delta_2/(\mathrm{AP} + \mathrm{I}) + \delta_3/(\mathrm{AP} + \mathrm{SP}) + \delta_4/(\mathrm{AP} + \mathrm{C}) + \delta_5/(\mathrm{AP} + \mathrm{AAP})]$.

(B1 in Table D-3) identifies $\epsilon = -0.350$. Monthly price elasticities are increased by approximately this margin for all models.

While we profess a slight preference for the real price models (particularly the Generalized Cobb-Douglas form), there is no strongly compelling reason for this selection. Both alternatives are included in this report so that users of these results may select the alternative which better meets their needs.

V. CONCLUSIONS: TOWARD APPLICATION

Motivations for developing a community water demand function included potential applications in:

- projecting future water demand for specific communities;
- valuing enhancements to municipal water supplies;
- establishing rate structures for allocating limited water supplies;
- evaluating water conservation measures;
- estimating the municipal costs and benefits resulting from proposed interbasin/intersectoral water transfers; and
- examining rate structures which include peak-load pricing.

In addition to providing important information for activating these applications, this study has produced fundamental descriptive information in Section III which is useful to state and local planners. Also, some of the empirical work of Section V has not been performed elsewhere. Most of these results are especially interesting and useful because of the very large dataset which provides a high degree of confidence in individual parameter estimates.

Overall statistical fit is not good, but that is not surprising in light of the results of other studies and the many probable data deficiencies. As an example of data problems, gallons per capita per day (Q) is the dependent variable in all regressions. Populations used as the divisor for this variable were projected, not actual, and may also exclude/include, in varying degrees, people out-of-city-limits receiving community water. The monthly water use reported by communities to the TWDB is really water production rather than consumption. Because of the changing amount of water in ground or elevated storage, production and consumption are unequal. Production is measured by one or more master meters (which are sometimes very inaccurate) or roughly estimated by the community. The TWDB attempts to net wholesale sales and industrial use out of these figures, but this task cannot be performed with precision. These and other data deficiencies, together with problems likely generated by omitted variables, produce a weaker than desired explanatory power.

In light of the reduced explanatory powers of the alternative demand models provided by this study, it is fortunate that most applications depend upon the tightly known parameter estimates instead of the full models. The remaining remarks of this report are intended to guide these applications. The majority of applications will likely depend on a single or a few parameter estimates, and most of these estimates have high *t* statistics (low standard errors) implying a high degree of confidence.

Demand projection can be pursued in a variety of ways depending upon what is known about the community(ies) in question. If nothing is known about the community's current rates or water use (AP, Q), one approach is to obtain Census and weather data (I, SP, AAP, mean C) for the community (either from original data sources or "interpolating" from data for nearby communities or using average Texas data from Tables C-3 or C-4 or some combination of these alternatives). Of course, the more customized the data is to the community, the better the expected projection. Substituting monthly values for these variables into one of the available models produces a demand function, Q = f(AP). Applications in **rate evaluation** and **policy analysis** require this function. If the application merely requires the projection of water use, the monthly AP values must be selected. The values listed in Table C-4 are possible selections. If a nominal-price model is being employed and a distant future water use projection is being sought, then the selected monthly average prices can be inflated by some percentage, perhaps that observed in Section III. Alternatively, with a real-price model, one could reasonably assume a more moderate increase or no increase in monthly AP's.

Demand projection with knowledge of the community's typical patterns of monthly consumption per capita and average price is pursued more easily. Each monthly Q and AP can be treated as a single point on the unknown monthly demand function, Q = f(AP). After selecting that month's elasticity estimate from any model, say the Generalized Cobb-Douglas model (Table 5 or D-5), the unknown function can be linearly approximated after obtaining slope from the identity

$$\frac{\partial Q}{\partial AP} = \epsilon \cdot \frac{Q}{AP}.$$

Or, knowledge of Q, AP, and ϵ permits an immediate logarithmic approximation about (Q, AP). Estimates or observations of I, SP, AAP, or C are unnecessary for either course of action.

The end result of all of these methods must be multiplied by population and days to obtain total water instead of gallons per capita per day. Use of the TWDB's extensive population projection model interfaces nicely here. Different scenarios (e.g. high, base, low) can always be obtained through appropriate choices of appropriate variables (C in the little-community-knowledge case, Q and AP in the good-knowledge case). The standard deviations given in Tables C-3 and C-4 offer valuable information assisting the selection of these scenarios.

Applications in **rate evaluation** and **policy analysis** are extensions of **demand projection** and naturally begin with one or more of the above methods. **Rate evaluations** can use community-specific demand functions to easily estimate the impact of proposed water/sewer rates upon monthly water consumption, consumer surplus, and utility revenues. Knowledge of income elasticities allows these evaluations to be performed by income classes so that the equity of new rates can be more readily assessed. Such analyses could also be conducted for alternate climate scenarios and thereby gauge, among other things, the merits of rate surcharges under drought conditions. Finally, the econometric work presented in this report has purposely employed monthly data so that TOY (time of year) rates can also be evaluated.

Two classes of **policy analyses** can be addressed with this work. The value of supply increments (achieved through physical supply development, water right acquisitions, interbasin or intersectoral transfers, etc.) can be estimated as consumer surplus areas as can the value of supply decrements (through groundwater mining, supply reallocation or transfers, etc.). As a related point, knowledge of the demand function and available supply allows either a market-clearing price or a water shortage/surplus to be estimated. This knowledge can be useful when faced with the cyclical, uncertain supply that typifies water systems.

Finally, the second class of feasible **policy analyses** addresses the impact of prospective technical shifts in demand. For example, the adoption of conservation techniques by households may be found (or postulated) to reduce demand uniformly by some specific amount or percentage. Knowledge of supply <u>and demand</u> conditions permits the evaluation of this shift in terms of impacts upon consumption, surplus measures, equilibrium rates, etc.

The remarks have hopefully illucidated and accelerated the application of these results. Opportunities for fruitful applications are numerous, and many planning activities can be assisted through such efforts.

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APPENDIX A

TEXAS A&M UNIVERSITY

RESIDENTIAL WATER DEMAND STUDY

1. Name and title of person completing the survey.

   ____________________/____________________

2. Your telephone number during office hours.

   (   ) ______________________________

   Area Code   Number   Extension

3. Would you like a free copy of the final report made available to you? (check one)

   ☐ Yes   ☐ No

4. When does your fiscal year start? ____________

   month/day

5. What units of water measurement do you use in billing residential customers? (check one)

   ☐ None (unmetered)   ☐ 100 cubic feet

   ☐ 1000 gallons   ☐ other (identify)

   ____

Directions:

a. Begin in Row 1 below the example entry in the Residential Water Rates table below.

b. In the "Date of Change" column enter the last date residential water rates changed prior to January 1, 1981.

c. In the "Base Rate" column, state the monthly base rate (minimum bill) residential water users pay.

d. Under "From" in the 1st Block, state the beginning amount for the block. Under "To", state the ending amount for that block. Under "$", state the rate or dollar amount per unit of water for that block.

e. Continue for as many succeeding blocks as needed.

f. In Row 2 enter the date rates changed next and the revised rates.

g. Continue for as many rows as needed until you have described present residential water rates. Use extra paper if necessary.

h. Follow the same procedure to describe sewer rates in the table to the right.

7. RECORD OF SEWER RATES, JAN. 1981 TO PRESENT

Date	Base Rate (Min. Bill)	1st Block			2nd Block		
		From	To	$	From	To	$
ROW 1							
ROW 2							
ROW 3							
ROW 4							
ROW 5							
ROW 6							

6. RECORD OF RESIDENTIAL WATER RATES FROM JANUARY 1981 TO PRESENT

Date of Change	Base Rate (Min. Bill)	1st Block			2nd Block			3rd Block			4th Block			5th Block			6th Block		
		From	To	$	From	To	$	From	To	$	From	To	$	From	To	$	From	To	$
EXAMPLE 10/1/79	4.00	5000	10000	.50	10000	40000	.30	40000	—	.25									
ROW 1																			
ROW 2																			
ROW 3																			
ROW 4																			
ROW 5																			
ROW 6																			

8. **Please estimate the percentage of your organization's 1986 water/sewer revenues which were used to fund nonwater and nonsewage city services.**

9. **What is the approximate *maximum* amount of water your system can produce (withdraw from the ground or convey from surface water impoundments) and treat in a single day?**

10. **Please list by month(s) and year(s) any periods during which your system was unable to satisfy demand *or* during which your community attempted to temporarily curtail demand (through news releases, alternate day watering programs, regulations, etc.).**

Thank you for completing the survey. Please use the enclosed envelope to return it to us.

Questions or comments can be related to Dr. Ronald C. Griffin at (409) 845-2334. Call collect if you wish.

APPENDIX B

Table B-1. Merging Information for the 221 Analyzed Communities.

Name	TWDB Code	Matching Weather Station Code for		
		Precipitation	Temperature	AAP
Alvin	016800	0204	0204	0204
Amarillo	017600	0211	0211	0211
Anahuac	024800	0235	0235	0235
Angleton	028800	0257	0257	0257
Anson	029800	8583	8583	8583
Aransas Pass	032800	7704	7704	0305
Arlington	035000	0337	0691	0337
Austin*	041010	0428	0428	0428
Ballinger	050700	0493	0493	0493
Bartlett	056800	3686	3686	8861
Bastrop	057600	2820	2820	0428
Beaumont	060200	0611	0613	0611
Bellaire	064800	4307	4307	4300
Bellville	067200	0655	1048	1048
Belton	068000	0665	0665	8910
Benavides	068800	0690	0690	3063
Benbrook	069600	0691	0691	0691
Big Lake*	072800	0779	0779	5859
Bishop	076000	1651	1651	2015
Boerne	084000	0902	0902	0902
Bogata	084800	6119	6119	6108
Booker	087200	0944	3225	0944
Borger	088000	0958	0958	0958
Bovina	090400	3368	3368	4098
Brazoria	095200	0257	0257	0257
Breckenridge	095900	1042	3668	3668
Brenham*	097600	1048	1048	1048
Bridge City	098000	7174	7174	7174
Bronte	098305	7669	7669	7669
Brownfield	099200	1128	1128	1128
Brownsville	100400	1136	1136	1136
Brownwood	100600	1138	1138	1138
Bryan*	102400	1889	1889	1889
Buffalo	106400	1188	4591	1188
Caldwell	128200	1314	1889	1889
Calvert	129800	1348	1348	1348
Canadian	132200	1421	1421	1421
Canyon*	133000	1430	1430	1430
Chandler	147000	0404	0404	0404
Cisco	153300	7327	7327	7327
Claude	157800	1778	1778	1430

(continued)

Table B-1. Continued.

Name	TWDB Code	Matching Weather Station Code for		
		Precipitation	Temperature	AAP
Cleburne	160200	1800	1800	1800
Cleveland	161000	1810	1810	1956
Coleman	165200	1875	1875	1875
Columbus	173800	1911	1911	1911
Comanche	176300	1914	7300	1914
Commerce	177000	6119	6119	6108
Conroe	180200	1956	1956	1956
Corpus Christi	185000	2015	2015	2015
Corsicana	186300	2019	2019	2019
Cross Plains	194600	7327	7327	7327
Crowley*	195600	0691	0691	0691
Crystal City	196200	2160	2160	2160
Dalworthington Gardens	214800	0691	0691	0691
Decatur*	217200	2334	1063	1063
Deer Park	218000	4315	4328	4315
Edgewood	253920	9800	9800	9800
Edinburg*	254000	5701	5701	5701
Edna	254200	2768	9364	2768
Eldorado	255800	2792	2792	2812
Electra	256600	2818	9729	2818
El Paso*	260300	2797	2797	2797
Euless	270450	2242	2242	2242
Everman	271800	0691	0691	0691
Farmers Branch	280800	2242	2242	2242
Farmersville	280825	3080	3734	3080
Forest Hill	293150	0691	0691	0691
Fort Stockton	296000	3280	3280	3280
Frankston	303200	0404	0404	0404
Fredericksburg	304000	3329	3329	3329
Freer	305600	3341	0690	3341
Friendswood	306100	0204	0204	0204
Gainesville	314600	3415	3415	3415
Galena Park	315800	4307	4307	4300
Galveston	316200	3430	3430	3430
Garland	318600	2244	2244	2244
George West	322610	3508	5661	3508
Giddings	324200	3525	1048	3525
Gladewater	327250	3525	5348	3525

(continued)

Table B-1. Continued.

Name	TWDB Code	Matching Weather Station Code for		
		Precipitation	Temperature	AAP
Glenn Heights	328575	2244	2244	2244
Goliad	331400	3620	7140	3620
Gonzales*	331950	3622	3622	3622
Graham	334350	3668	3668	3668
Granbury	334600	5243	0691	5243
Grand Saline	337000	9800	9800	9800
Grapevine	340200	3691	3691	3691
Groesbeck	344150	5869	5869	5869
Hallettsville	365200	3873	3873	3873
Hallsville	366000	5348	5348	4081
Hamlin	367750	3890	7782	7782
Harker Heights	368770	4792	4792	8910
Harlingen	368810	3943	3943	3943
Hempstead	379600	9448	1048	9448
Hewitt	385200	4122	5757	4122
Hitchcock*	391200	3430	3430	3430
Holliday	392440	4093	4093	4093
Hondo	393200	4256	4256	2360
Howe	398800	0262	5094	0262
Huntsville*	410000	4382	4382	4382
Hutchins	412400	3133	3133	3133
Iraan	423000	0482	0482	0482
Irving*	425400	2244	2244	2244
Jasper	434400	4563	7936	4563
Keene	459400	1800	1800	1800
Kemp	461465	4705	4705	4705
Kennedale	462600	0691	0691	0691
Kermit	463400	9830	9830	9830
Kingsville*	466800	4810	4810	4810
Knox City	468200	9163	9163	6740
Lacy-Lakeview	478200	9419	9419	9419
La Grange	479600	4903	4903	4903
La Marque	483200	3430	3430	3430
Laredo*	486190	5060	5060	5060
League City	488400	4307	4307	4300
Liberty	494800	5196	5196	5196
Lindale	497200	5954	5348	5954
Little River-Academy	504400	8910	8910	8910
Lockney	507000	7079	7079	7079
Longview	512010	5341	5348	5341
Los Fresnos	514500	1136	1136	1136
Lufkin	519600	5424	5424	5424

(continued)

Table B-1. Continued.

Name	TWDB Code	Matching Weather Station Code for Precipitation	Temperature	AAP
Madisonville	526200	5477	5477	5477
Mason	540600	5650	5650	5650
McGregor*	547800	5757	5757	5757
Memphis	555800	5821	5821	5821
Midland	565400	5890	5890	5890
Mineola	571000	5954	0404	5954
Mont Belvieu	576200	0235	0235	0235
Moody	577400	5757	5757	5757
Moulton	580600	3183	3183	3183
Mount Pleasant	582250	6108	6108	6108
Muenster	584600	6130	3415	6130
Muleshoe*	585400	6135	6135	6135
Munday	586200	6146	6146	6146
Nassau Bay	593050	4307	4307	4300
Navasota	596800	9491	9491	9491
New Boston	601000	6270	8942	5667
Nixon	604800	6368	6368	6368
Odem	619200	2015	2015	2015
Odessa*	619550	6502	6502	6502
Olton	624400	6644	7079	7079
Orange Grove	628400	7704	7704	0305
Paducah	639000	6740	6740	6740
Pampa*	642200	6776	6776	6776
Panhandle	647800	6785	6785	6785
Panorama Village	650230	1956	1956	1956
Paris	651250	6794	6794	6794
Perryton	657400	6953	6950	6953
Petersburg	658200	3214	3214	3214
Pharr	663800	5702	5702	5701
Pinehurst	683180	6664	7174	6664
Pittsburg	683450	7066	2225	7066
Plainview*	684600	7079	7079	7079
Port Arthur	690350	7174	7174	7174
Port Lavaca	691000	7182	7182	7182
Post	692600	7206	7206	7206
Quanah	708800	7336	7336	7336
Queen City	709600	8942	8942	5667
Quitman	712000	7363	4483	7363
Ralls	717800	2121	2121	2121
Ranger	718560	7633	7633	7633

(continued)

Table B-1. Continued.

		Matching Weather Station Code for		
Name	TWDB Code	Precipitation	Temperature	AAP
Rankin	718590	5707	5707	5707
Refugio	722600	7704	7704	7529
Richardson*	724200	7588	2244	7588
Rio Grande City	728600	7622	7622	7622
Rio Hondo	728650	3943	3943	3943
Robinson	733600	9417	9417	9419
Roma-Los Saenz	741100	3060	3060	7622
Roscoe	742600	7743	7743	7743
Rosenberg*	743400	8996	8996	0204
Rusk	754600	7841	7841	7841
Sabinal	759600	7873	1007	7873
Saginaw	761200	2677	2677	2242
San Antonio*	764200	7945	7945	7945
San Diego	767400	0690	0690	3063
San Marcos	769000	7497	7497	7983
Schertz	778200	7945	7945	7945
Schulenburg	778600	8126	1911	8126
Seabrook	778800	4307	4307	4300
Seagraves	781000	8201	8201	8201
Seminole	783400	8201	8201	8201
Seymour	788200	8221	8221	8221
Shallowater	788800	5411	5411	5411
Shamrock	789000	8235	8236	8235
Shiner	793800	9952	9952	9952
Smithville	802600	8415	8415	3183
Sonora	805800	8449	8449	8449
Sour Lake	806000	0613	0613	0611
Spearman	817800	8523	8523	8523
Stanton	823400	5891	5891	5891
Stockdale	825800	8658	6368	6368
Sudan	827400	6137	6137	6135
Sugar Land	828050	8728	8728	8728
Sulphur Springs	828100	8743	8743	8743
Sweeny	835400	3340	3340	3340
Taft	841200	1651	1651	2015
Tahoka*	842000	8818	8818	8818
Temple*	846000	8910	8910	8910
Texas City	849200	3430	3430	3430
Thorndale	865000	9001	8861	8861
Troup	875600	4081	4081	4081
Tyler*	881200	6119	6119	6108
Valley Mills	895000	9419	9419	9419

(continued)

Table B-1. Continued.

Name	TWDB Code	Matching Weather Station Code for Precipitation	Temperature	AAP
Van Horn	899000	7920	7920	9295
Victoria*	902400	9364	9364	9364
Waco	911600	9419	9419	9419
Waller	916000	9448	4300	9448
Waskom*	919200	5348	5348	4081
Waxahachie	920800	9522	9522	9522
Webster	922000	8449	5650	8449
Weimar	922400	1911	1911	1911
Wellington	924000	1761	1761	1761
West	927200	9715	9715	9715
West Columbia	928800	0257	0257	0257
Wheeler	939200	9662	5770	6776
White Deer	940000	1000	1000	0211
Wichita Falls	944456	9729	9729	9729
Willis	948800	1956	1956	1956
Wink	952000	9830	9830	9830
Winters*	952900	9847	9847	9847
Yoakum	967600	9952	9952	9952

*In the pretest subsample used by Griffin and Chang.

Table B-2. Cross Sectional Data for the 221 Analyzed Communities.

Name	1985 Population	Income	% Spanish	AAP
Alvin	18692	7.876	5.27	47.99
Amarillo	164879	7.733	3.31	19.10
Anahuac	1818	7.410	3.26	50.06
Angleton	15344	8.581	4.21	52.28
Anson	2993	5.638	11.45	23.23
Aransas Pass	8063	5.524	5.98	43.61
Arlington	223508	8.744	1.33	33.24
Austin*	424120	7.150	8.95	31.50
Ballinger	4586	5.928	10.91	22.11
Bartlett	1654	4.746	10.33	34.21
Bastrop	5280	5.524	6.28	31.50
Beaumont	121544	7.518	0.86	54.50
Bellaire	15080	11.080	2.94	44.77
Bellville	3521	8.659	0.56	39.72
Belton	12161	5.058	9.72	33.75
Benavides	2001	4.307	9.55	25.77
Benbrook	17727	9.868	1.51	30.61
Big Lake*	4095	6.140	19.37	18.04
Bishop	3861	6.266	6.58	30.18
Boerne	4685	5.789	10.53	32.24
Bogata	1568	4.670	0.00	45.50
Booker	1439	6.991	4.27	20.19
Borger	16411	8.025	1.89	19.33
Bovina	1584	4.664	35.29	16.01
Brazoria	3386	7.189	2.48	52.28
Breckenridge	7279	5.998	4.03	28.01
Brenham*	13187	5.937	1.56	39.72
Bridge City	7231	7.927	1.11	52.79
Bronte	1074	6.410	12.00	20.67
Brownfield	10930	5.896	10.03	16.97
Brownsville	98091	4.093	18.62	25.44
Brownwood	19409	5.835	6.08	26.10
Bryan*	60084	6.348	6.42	39.08
Buffalo	2142	5.682	0.26	42.23
Caldwell	3576	5.943	7.02	39.08
Calvert	1709	3.899	4.73	34.26
Canadian	3791	7.442	4.76	20.09
Canyon*	11429	6.089	3.45	18.37
Chandler	1741	6.081	0.00	39.43
Cisco	4598	5.124	3.25	24.66
Claude	1061	7.250	0.00	18.37
Cleburne	22936	6.698	1.81	32.37

(continued)

Table B-2. Continued.

Name	1985 Population	Income	% Spanish	AAP
Cleveland	6740	5.741	0.64	46.60
Coleman	6158	5.352	5.80	26.94
Columbus	4258	6.655	1.15	41.45
Comanche	4081	5.903	5.92	27.73
Commerce	7945	5.121	1.18	45.50
Conroe	19028	7.632	2.34	46.60
Corpus Christi	256905	6.768	10.77	30.18
Corsicana	23765	6.311	2.63	36.63
Cross Plains	1198	4.874	0.97	24.66
Crowley*	7317	6.553	2.10	30.61
Crystal City	8434	2.930	21.32	21.34
Dalworthington Gardens	1338	11.605	0.00	30.61
Decatur*	4714	6.253	5.14	28.86
Deer Park	24959	8.933	2.04	49.60
Edgewood	1507	5.694	1.91	42.39
Edinburg*	31374	4.278	14.62	23.04
Edna	5689	5.924	11.43	40.21
Eldorado	2395	5.693	5.05	19.02
Electra	3583	6.166	1.09	26.80
El Paso*	480143	5.389	14.95	7.82
Euless	29151	8.482	1.47	29.45
Everman	5878	6.868	3.23	30.61
Farmers Branch	27358	9.775	3.66	29.45
Farmersville	2890	5.904	3.98	40.55
Forest Hill	13768	6.529	3.96	30.61
Fort Stockton	10096	5.708	21.88	12.21
Frankston	1478	6.254	0.40	39.43
Fredericksburg	7375	6.033	2.03	28.67
Freer	3729	4.670	2.14	24.43
Friendswood	17533	10.997	0.92	47.99
Gainesville	14161	6.659	1.14	32.99
Galena Park	10127	7.110	14.97	44.77
Galveston	61806	7.101	6.37	40.24
Garland	165626	8.078	2.86	34.16
George West	2716	5.641	6.81	27.59
Giddings	4880	5.964	4.96	37.63
Gladewater	7455	5.583	0.00	37.63
Glenn Heights	1169	7.710	0.00	34.16
Goliad	2039	5.398	19.75	33.54
Gonzales*	8000	4.811	6.72	33.15
Graham	9620	8.010	0.82	28.01

(continued)

Table B-2. Continued.

Name	1985 Population	Income	% Spanish	AAP
Granbury	4941	7.118	0.39	28.76
Grand Saline	2951	5.899	1.11	42.39
Grapevine	17550	8.899	0.81	31.65
Groesbeck	3817	5.873	1.21	38.28
Hallettsville	2608	6.199	0.00	38.40
Hallsville	2120	6.594	2.25	44.74
Hamlin	3159	6.450	10.99	22.46
Harker Heights	8626	6.453	3.29	33.75
Harlingen	53733	4.940	18.43	26.48
Hempstead	3807	5.552	2.75	40.74
Hewitt	7554	7.487	0.88	32.54
Hitchcock*	6345	6.914	2.18	40.24
Holliday	1478	5.853	0.44	30.09
Hondo	6251	4.364	15.01	17.19
Howe	2347	6.630	0.00	36.65
Huntsville*	31110	4.190	4.60	44.20
Hutchins	3813	5.820	5.57	36.02
Iraan	1874	6.658	6.26	13.47
Irving*	124117	8.428	3.02	34.16
Jasper	7155	5.734	0.67	50.59
Keene	3313	5.316	3.42	32.37
Kemp	1253	5.310	0.39	38.18
Kennedale	3005	6.119	3.43	30.61
Kermit	8495	6.141	19.43	11.02
Kingsville*	29804	5.445	9.86	27.50
Knox City	1727	5.942	9.57	21.96
Lacy-Lakeview	2908	5.495	4.00	30.95
La Grange	4205	6.112	3.13	37.52
La Marque	15552	7.776	2.12	40.24
Laredo*	107760	3.663	7.83	20.14
League City	22723	8.734	2.06	44.77
Liberty	8440	7.980	0.83	50.65
Lindale	2770	6.411	0.18	40.35
Little River-Academy	1174	6.264	2.42	33.75
Lockney	2186	4.664	23.31	18.97
Longview	73981	7.370	1.07	46.47
Los Fresnos	2740	4.780	24.67	25.44
Lufkin	30857	6.683	3.40	41.48
Madisonville	4065	5.786	1.64	41.06
Mason	2090	4.921	14.38	24.94
McGregor*	4732	5.391	8.40	33.77
Memphis	2909	5.367	5.97	20.34

(continued)

Table B-2. Continued.

Name	1985 Population	Income	% Spanish	AAP
Midland	93385	10.350	7.14	13.70
Mineola	4917	6.819	0.16	40.35
Mont Belvieu	1765	7.925	1.20	50.06
Moody	1517	4.179	5.27	33.77
Moulton	1008	5.312	4.66	37.41
Mount Pleasant	11689	6.507	2.14	45.50
Muenster	1347	6.706	0.00	33.37
Muleshoe*	5080	5.404	17.88	16.08
Munday	1783	6.822	13.98	24.31
Nassau Bay	4820	14.526	0.48	44.77
Navasota	7492	5.162	3.58	39.32
New Boston	4835	6.083	0.82	46.96
Nixon	2217	4.249	21.66	32.56
Odem	2717	5.444	4.58	30.18
Odessa*	101311	7.949	8.80	13.54
Olton	2065	4.632	22.59	18.97
Orange Grove	1552	5.144	11.30	43.61
Paducah	2041	6.031	3.28	21.96
Pampa*	22085	7.846	1.79	19.57
Panhandle	2311	7.435	1.17	19.72
Panorama Village	1532	14.137	0.08	46.60
Paris	26294	5.676	0.12	44.97
Perryton	9151	8.501	2.01	18.77
Petersburg	1554	4.016	17.62	18.96
Pharr	25231	3.327	13.78	23.04
Pinehurst	2892	7.521	0.20	59.20
Pittsburg	4444	6.626	0.14	43.29
Plainview*	22522	5.862	18.11	18.97
Port Arthur	63150	6.394	1.65	52.79
Port Lavaca	11990	6.709	9.86	42.21
Post	4049	5.375	18.10	19.42
Quanah	3890	6.828	4.34	23.37
Queen City	1737	4.646	0.63	46.96
Quitman	2053	6.718	0.00	42.03
Ralls	2221	5.475	23.45	20.48
Ranger	3381	4.771	1.36	27.24
Rankin	1506	6.381	9.21	12.73
Refugio	3500	6.354	7.41	38.76
Richardson*	80018	10.685	0.53	35.48
Rio Grande City	9874	3.216	12.81	20.57
Rio Hondo	2040	4.984	23.07	26.48

(continued)

Table B-2. Continued.

Name	1985 Population	Income	% Spanish	AAP
Robinson	6545	6.913	1.89	30.95
Roma-Los Saenz	4192	2.299	3.16	20.57
Roscoe	1613	5.686	20.02	23.35
Rosenberg*	20489	6.610	15.20	47.99
Rusk	4656	6.070	1.58	44.61
Sabinal	2081	3.585	22.77	25.53
Saginaw	7221	6.752	3.10	29.45
San Antonio*	875786	5.593	11.26	29.13
San Diego	5697	3.384	5.78	25.77
San Marcos	28596	3.849	13.45	34.31
Schertz	7769	6.207	4.94	29.13
Schulenburg	2420	5.550	0.57	38.56
Seabrook	4870	9.867	1.65	44.77
Seagraves	2642	5.610	15.45	15.80
Seminole	6793	6.311	7.17	15.80
Seymour	3622	5.784	2.90	25.66
Shallowater	2144	5.937	8.95	17.76
Shamrock	2719	6.406	4.30	22.58
Shiner	2165	5.010	1.58	36.17
Smithville	4624	5.412	3.43	37.41
Sonora	4106	8.725	1.32	20.70
Sour Lake	2045	6.667	0.00	54.50
Spearman	3592	7.833	5.39	19.15
Stanton	2683	5.437	21.85	14.13
Stockdale	1303	4.710	16.69	32.56
Sudan	1020	5.672	9.35	16.08
Sugar Land	15631	10.063	4.23	43.87
Sulphur Springs	14290	6.251	0.34	44.16
Sweeny	3740	8.213	4.21	51.01
Taft	3530	5.890	14.97	30.18
Tahoka*	2977	5.117	10.05	18.31
Temple*	46019	6.611	5.88	33.75
Texas City	43151	7.530	3.80	40.24
Thorndale	1321	5.858	6.88	34.21
Troup	2088	5.678	0.63	44.74
Tyler*	75794	7.376	2.46	45.50
Valley Mills	1377	5.719	1.29	30.95
Van Horn	2888	3.952	12.16	11.06
Victoria*	55854	7.087	12.37	36.90
Waco	105264	5.935	5.05	30.95
Waller	1763	6.334	3.20	40.74

(continued)

Table B-2. Continued.

Name	1985 Population	Income	% Spanish	AAP
Waskom*	2206	6.480	0.65	44.74
Waxahachie	17147	6.128	5.29	36.25
Webster	3052	7.585	4.34	20.70
Weimar	2128	6.470	1.64	41.45
Wellington	2590	5.274	5.50	21.45
West	2545	5.781	0.56	32.70
West Columbia	4463	7.527	2.51	52.28
Wheeler	1759	9.187	0.70	19.57
White Deer	1333	6.828	0.83	19.10
Wichita Falls	98479	6.768	3.23	26.73
Willis	2496	5.021	0.48	46.60
Wink	1597	5.395	6.31	11.02
Winters*	3179	5.302	8.88	24.34
Yoakum	6367	5.377	10.23	36.17

*In the pretest subsample used by Griffin and Chang.

APPENDIX C

Table C-1. Correlation Matrix for Nonlog Variables.

	Q	AP	APxC	PO	POxC	-APS	-APSxC	I	SP	C	AAP
Q	1.00										
AP	-0.35	1.00									
APxC	-0.10	0.84	1.00								
PO	0.41	-0.45	-0.28	1.00							
POxC	0.27	-0.40	-0.43	0.91	1.00						
-APS	-0.27	0.79	0.68	-0.24	-0.21	1.00					
-APSxC	-0.15	0.73	0.79	-0.16	-0.23	0.94	1.00				
I	0.02	0.11	0.08	0.01	0.02	0.15	0.13	1.00			
SP	0.05	-0.23	-0.18	0.06	0.05	-0.18	-0.15	-0.42	1.00		
C	0.50	-0.13	0.38	0.22	-0.12	-0.09	0.18	-0.07	0.07	1.00	
AAP	-0.20	0.23	0.22	-0.07	-0.09	0.31	0.30	0.27	-0.49	0.01	1.00

Table C-2. Correlation Matrix for Basic Log Variables.

	ln Q	ln AP	AP	ln I	SP	ln C	ln AAP
ln Q	1.00						
ln AP	-0.43	1.00					
AP	-0.38	0.95	1.00				
ln I	0.00	0.16	0.13	1.00			
SP	0.05	-0.24	-0.23	-0.45	1.00		
ln C	0.47	-0.15	-0.13	-0.08	0.07	1.00	
ln AAP	-0.18	0.29	0.25	0.25	-0.51	0.03	1.00

Table C-3. Data Means and Standard Deviations

Variable	Mean	Standard Deviations
Q	169.27	67.75
AP	1.983	0.840
I	6.397	1.680
SP	6.071	6.467
C	1800.59	418.15
AAP	32.46	10.81

Table C-4. Minimums, Means, Maximums, and Standard Deviations for Selected Variables by Month.

Month	Q				C				Nominal AP				Real AP			
	Min	Mean	Max	S.D.	Min	Mean	Max	S.D.	Min	Mean	Max	S.D.	Min	Mean	Max	S.D.
Jan	35.60	138.01	387.01	41.62	870.60	1287.13	1940.91	174.17	0.324	2.010	6.989	0.820	0.324	1.783	6.212	0.699
Feb	45.20	138.14	555.03	43.04	818.64	1262.36	1809.6	156.82	0.334	2.071	6.662	0.851	0.330	1.829	5.791	0.723
Mar	54.97	138.89	385.44	43.62	1118.88	1639.60	2222.08	196.98	0.346	2.015	6.638	0.827	0.340	1.776	5.641	0.699
Apr	45.32	161.30	398.60	52.56	1346.24	1843.17	2319.90	181.13	0.308	1.965	6.365	0.833	0.301	1.723	5.497	0.706
May	32.60	172.99	454.06	60.18	1329.60	1966.17	2425.13	204.80	0.283	1.912	6.151	0.812	0.274	1.668	5.273	0.687
Jun	35.43	192.92	461.30	68.25	1418.00	2074.84	2604.90	204.85	0.263	1.883	6.274	0.807	0.252	1.633	5.239	0.681
Jul	34.17	227.72	548.49	84.71	1632.00	2358.64	2763.96	177.42	0.199	1.805	5.987	0.802	0.189	1.558	5.144	0.672
Aug	62.15	234.71	730.73	83.20	1502.60	2392.27	2757.45	198.41	0.182	1.796	5.987	0.795	0.171	1.545	5.043	0.664
Sep	77.89	202.18	663.57	68.84	1484.28	2098.68	2526.00	167.61	0.288	1.886	6.148	0.810	0.269	1.615	5.106	0.672
Oct	43.61	153.25	425.22	46.41	1212.96	1789.22	2411.49	210.97	0.311	2.073	6.622	0.852	0.290	1.771	5.442	0.703
Nov	46.81	138.01	336.04	39.64	1138.83	1570.99	2219.40	184.01	0.285	2.185	6.740	0.872	0.264	1.862	5.602	0.715
Dec	20.96	137.98	556.40	45.26	644.09	1362.84	2106.90	230.73	0.309	2.179	6.719	0.876	0.286	1.857	5.919	0.721

APPENDIX D

Community Water Demand Estimates
and
Elasticities Using Real Prices

Table D-1. Consumer Price Index, 1981-86.

Year	Month	CPI	Year	Month	CPI
1981	January	260.5	1984	January	305.2
	February	263.2		February	306.6
	March	265.1		March	307.3
	April	266.8		April	308.8
	May	269.0		May	309.7
	June	271.3		June	310.7
	July	274.4		July	311.7
	August	276.5		August	313.0
	September	279.3		September	314.5
	October	279.9		October	315.3
	November	280.7		November	315.3
	December	281.5		December	315.5
1982	January	282.5	1985	January	316.1
	February	283.4		February	317.4
	March	283.1		March	318.8
	April	284.3		April	320.1
	May	287.1		May	321.3
	June	290.6		June	322.3
	July	292.2		July	322.8
	August	292.8		August	323.5
	September	293.3		September	324.5
	October	294.1		October	325.5
	November	293.6		November	326.6
	December	292.4		December	327.4
1983	January	293.1	1986	January	328.4
	February	293.2		February	327.5
	March	293.4		March	326.0
	April	295.5		April	325.3
	May	297.1		May	326.3
	June	298.1		June	327.9
	July	299.3		July	328.0
	August	300.3		August	328.6
	September	301.8		September	330.2
	October	302.6		October	330.5
	November	303.1		November	330.8
	December	303.5		December	331.1

Source: U.S. Department of Commerce, 1987, p. 24.

Table D-2. Parameter Estimates for the Predominately Linear Models*

Q =	A1	A2	A3	A4
Intercept	10.33 (1.64)	106.61 (27.78)	4.71 (0.77)	16.66 (2.42)
AP	27.30 (9.21)	-27.76 (-38.29)	27.23 (8.67)	24.81 (5.04)
APxC	-0.0310 (-19.15)		-0.0258 (-15.20)	-0.0332 (-12.41)
PO			-39.36 (-5.97)	
POxC			0.0503 (13.62)	
-APS				5.14 (0.67)
-APSxC				0.00458 (1.10)
I	4.20 (13.33)	4.08 (12.75)	3.65 (12.12)	3.98 (12.60)
SP	-1.21 (-13.22)	-1.21 (-13.05)	-1.16 (-13.30)	-1.30 (-14.16)
C	0.128 (43.18)	0.0760 (64.49)	0.137 (47.12)	0.130 (39.45)
AAP	-1.36 (-26.32)	-1.39 (-26.56)	-1.32 (-26.55)	-1.45 (-27.37)
F	1338.7	1488.0	1243.3	1015.3
R^2	0.40	0.38	0.45	0.40
n	12050	12050	12050	12050

*t statistics in parentheses

Table D-3. Parameter Estimates for the Logarithmic Models*

ln Q =	B1	B2	B3
Intercept	0.706 (8.12)	0.818 (9.16)	0.573 (6.54)
ln AP	-0.350 (-50.53)		-0.562 (-25.31)
AP		-0.173 (-43.96)	0.124 (10.05)
ln I	0.128 (11.10)	0.109 (9.26)	0.139 (11.98)
SP	-0.00669 (-13.33)	-0.00710 (-13.82)	-0.00621 (-12.36)
ln C	0.649 (60.07)	0.671 (60.97)	0.644 (59.74)
ln AAP	-0.154 (-18.55)	-0.183 (-21.89)	-0.143 (-17.18)
F	1618.2	1446.9	1376.5
R^2	0.40	0.38	0.41
n	12050	12050	12050

*t statistics in parentheses

Table D-4. Parameter Estimates for the Generalized Cobb-Douglas Form

ln Q =	Estimator	*t*
Intercept	-5.09	-17.35
ln AP	-0.584	-23.07
ln (AP + I)	0.480	3.33
ln (AP + SP)	0.117	7.60
ln (AP + C)	123.95	6.55
ln (AP + AAP)	-0.557	-1.54
ln I	-0.104	-0.92
ln (I + SP)	-0.354	-8.13
ln (I + C)	71.30	8.96
ln (I + AAP)	-0.957	-5.10
SP	0.0105	3.54
ln (SP + C)	17.97	6.16
ln (SP + AAP)	-0.540	-8.92
ln C	-243.80	-12.41
ln (C + AAP)	32.31	18.97
ln AAP	1.06	3.01
F	633.78	
R^2	0.44	
n	12050	

Table D-5. Monthly Real Price Elasticities

Month	Model A1	Model B2	Model B3	Model B4
January	-.16	-.31	-.34	-.31
February	-.16	-.32	-.34	-.30
March	-.30	-.31	-.34	-.35
April	-.32	-.30	-.35	-.37
May	-.32	-.29	-.36	-.38
June	-.31	-.28	-.36	-.39
July	-.31	-.27	-.37	-.41
August	-.31	-.27	-.37	-.41
September	-.30	-.28	-.36	-.39
October	-.33	-.31	-.34	-.36
November	-.29	-.32	-.33	-.33
December	-.20	-.32	-.33	-.31
ANNUAL	-.29	-.30	-.35	-.37