EFFECTIVENESS OF RESIDENTIAL WATER

CONSERVATION PRICE AND NONPRICE PROGRAMS

FINAL REPORT

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EFFECTIVENESS OF RESIDENTIAL WATER CONSERVATION PRICE AND NONPRICE PROGRAMS

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FOREWORD

The AWWA Research Foundation is a nonprofit corporation dedicated to the implementation of research efforts to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of grass-roots consultation with members, utility subscribers, and working professionals. Under the umbrella of a Five-Year Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection.

This publication is a result of one of those sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry's centralized research program but also as a tool to enlist the further support of the non-member utilities and individuals.

Projects are managed closely from their inception to the final report by the foundation's staff and a large cadre of volunteers who willingly contribute their time and expertise. The foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. Funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver. The program offers a cost-effective and fair method for funding research in the public interest.

For the past 20 years, many water utilities have implemented water conservation measures in response to supply shortages, to extend the life of treatment facilities, and to help combat droughts. In order to implement the most appropriate measures or mix of measures, information about consumer response to various programs is essential. Through the use of three different water demand models, this study evaluated the effectiveness of both price and nonprice conservation programs. Consumer responsiveness to changes in water price is analyzed as well as the change in water demand resulting from the implementation of nonprice conservation measures. The results of this study will aid any water agency with their conservation programs.

ACKNOWLEDGMENTS

The research team first wishes to express its sincere appreciation to the seven utilities and their staff members who participated in the study: Denver Water, City of Broomfield, Los Angeles Department of Water and Power, San Diego Water Utilities Department, and the water departments in the Cities of Albuquerque, Las Cruces and Santa Fe. We are especially grateful for the outstanding efforts and assistance provided by John Loughry, Tom Clark and Liz Gardener at Denver Water; Diane Cooper at Broomfield Water Department; Richard West, Pacience Dungo, George Martin and Margaret Pollyea at Los Angeles Water and Power Department; Marsi Steirer with San Diego Water Utilities Department; Norman Gaume, Jean Witherspoon, Steve Falk with the City of Albuquerque; Bill McKinney, Ken Needham, Joyce Kinnear and Jim Davila with Las Cruces; Emily Haley and Joseph Gonzales with the City of Santa Fe. This study was made possible by their willing cooperation and participation.

A special note of appreciation to Doug Gegax, New Mexico State University, for his valuable contributions regarding statistical analysis and econometric modeling of public utility pricing. We also thank Betty Olson, University of California at Irvine and John Tschirhart, University of Wyoming, for their participation in the development of this research and helpful recommendations.

The Powell Consortium and in particular the Water Resources Research Institutes and directors -- Steven Gloss, University of Wyoming, Tom Bahr, New Mexico State University, and Robert Ward, Colorado State University -- were instrumental in making this study possible. Many thanks for their recognition of the importance of this research and for their continuing encouragement and financial support.

Finally, the researchers wish to thank the American Water Works Association Research Foundation for its support of this study and express our sincere appreciation for guidance provided by project officers Kim Hout-Garrity, Kathryn Martin and Albert Ilges and the diligent review and valuable suggestions provided by each member of the AWWARF Project Advisory Committee: Clive Jones of Economic Data Resources; David LaFrance, Manager of Rate Administration, Denver Water; and William Maddaus of Maddaus Water Management. We also gratefully acknowledge and thank Dan Bishop with Montgomery Watson, and Michael Ozog, Water Utilites Department, Fort Collins, Colorado for their external reviews and valuable comments.

EXECUTIVE SUMMARY

Short-term recurrent drought and projected long-term demand-supply problems compel municipal water suppliers to consider water conservation measures. Conservation measures encourage consumers to use water more efficiently, reducing the quantity used to meet the same needs. Conservation induced reductions in individual and system wide water demand can be used to alleviate temporary water shortages; avoid increased water supply, treatment, system expansion and consumer costs; and extend the ability of existing supplies and system capacity to meet current and growing demands.

Over the past decade an increasing number of utilities have changed from declining block rate pricing to more conservation-oriented uniform and inclining rate structures where the price per unit remains the same or increases as water consumption increases. By 1994 the number of water providers using declining rate structures was less than 40 percent, down from 60 percent in 1986, and the number of providers using inclining rate structures had increased from eight percent in 1986 to more than 22 percent in 1994. Utilities nationwide are also using nonprice conservation programs as a substitute, or in addition, to price conservation programs in an effort to reduce residential demand.

RESEARCH NEED AND OBJECTIVES

Accurate information about consumer response to conservation programs is critical for selecting and implementing appropriate demand-side management strategies that will effectively encourage conservation in the long-term and that can be used to manage cyclical drought-induced supply shortages. Accurate knowledge about residential consumer's responses to conservation programs is also important in forecasting long-term demand, managing water supplies, determining acquisition requirements, formulating financial management decisions and for integrated resource management and planning. Utility managers need to know if and how residential water demand changes in response to demand side mangement programs, that is, how do consumers perceive and respond to changes in prices and rate structures and to nonprice conservation measures. However, the effects of conservation programs such as multi-part tariffs and inclining or inverted block rate structures upon residential consumption in different regions are not well understood even though there is an extensive body of literature dealing with this issue. Further, the synergistic effects of price and non-price programs are not well understood and there is very little literature dealing with this issue.

The purpose of this study is to build upon and extend previous water conservation research efforts to evaluate the effects of price and nonprice conservation programs on residential water demand in different urban areas of the southwestern United States. The primary research objectives are to: (1) develop residential water demand models to examine the effectiveness of price and nonprice programs; (2) develop and document a database of residential water demand in selected study areas; (3) evaluate the effectiveness of price and nonprice conservation programs using the water demand models and database developed for this study; and (4) examine the applicability of extending regional water demand relationships and results of conservation program effectiveness to other cities in the region. Specific issues examined on a regional, seasonal and individual city basis include:

- How responsive are consumers to changes in the price of water?
- Are consumers responding to the average price, marginal price, or some combination of the two?
- How does demand change or respond to the implementation of nonprice conservation programs?
- Is it appropriate to model and apply results on effectiveness to other cities in the region?

The scope in terms of number and cross-section of cities, detail of observations (monthly time periods), length of time covered and inclusion of price and nonprice programs, combined with the analytical techniques, contribute to making this one of the most comprehensive studies conducted on residential water use and the effectiveness of conservation programs. The research techniques and results of this evaluation will benefit water utilities and consumers through lower costs and more secure water supplies resulting from improved understanding and better planning and implementation of residential price, rate structure and nonprice conservation programs.

RESEARCH APPROACH

The following is a summary the research steps and approach used in this study.

Development of Water Demand Models

Evaluation of changes in residential water use and conservation policies implicitly or explicitly requires a model of consumer choice, that is, a model of water demand. Previous water demand estimation study methods, advances and limitations were reviewed and, building upon and extending this research, three water demand models are developed to investigate consumer response to price and nonprice conservation programs and other factors that may influence demand.

The first model (Regional) assumes that consumers in different cities respond similarly across the region and throughout the year to rate structures, price levels, nonprice conservation programs, climate, income and other factors. The second model (Season Specific) is designed to investigate seasonal variations in consumer response across the region to changes in rate structure, price levels, nonprice conservation programs, climate, income and other factors. The third model (City /Season Specific) is designed to investigate individual city and seasonal variations in consumer response to rate structure, price levels, nonprice conservation programs, climate, income and other factors.

Study Areas, Data Collection and Development of a Water Demand Database

Seven study areas were selected, and with the cooperation of water utilities in three southwestern states, information on residential water consumption, rate structures, revenue and nonprice conservation programs covering the period from 1984 through mid-1995 was collected. The study area cities are: Los Angeles and San Diego, California; Broomfield and Denver, Colorado; and Albuquerque, Las Cruces and Santa Fe, New Mexico. Similarities and differences in residential water use, prices and rate structures, climatic conditions and socioeconomic characteristics across the study areas provide an excellent cross-section of cities in the southwestern United States. These cities also exhibit a wide range of nonprice conservation programs, from cities that have numerous concurrent conservation programs to cities that have yet to implement nonprice conservation programs.

A database of the residential water demand information was created and consistent series of monthly observations for all of the water demand variables for each study area were developed and refined. Computational adjustments were required to develop consistent data series from billing and other reporting period observations and to verify and correct anomalies in reported data. The data gathered for this research and data development and adjustment procedures are described in detail in a separate report entitled *Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database* (1997). Copies of this report may be obtained through the American Water Works Association Research Foundation (Denver, Colorado) and The Powell Consortium Water Resource Research Institutes (contact: Wyoming Water Resource Center, University of Wyoming, Laramie, Wyoming; or New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces, New Mexico).

Water Demand Model Estimation and Analysis

Each of the three water demand models is tested, refined and analyzed using maximum likelihood regressions of the pooled 10-year time series, cross-sectional database. The results of each of the models are reported and coefficient values are analyzed for statistical significance, theoretical consistency and magnitude. Particular attention is given to analyzing the price elasticity of water demand (responsiveness) and consumer recognition of conservation pricing programs. The issue of consumer recognition and perception of price programs involves the following questions: Are consumers responding to the average price of water consumed? or as is assumed by economic theory and proponents of conservation through increasing block-rate-price structures, Do consumers perceive and respond to increasing block-rate structures (marginal prices) by lowering their use? In addition to consumer response to price programs, nonprice conservation programs are evaluated for overall significance and effect on water demand.

Evaluation of Regional Applicability and Water Demand Models Predictions

The results of the three models are examined to identify relationships and trends in regional and city specific water demand. The Regional, Season Specific and City/Season models are also evaluated to determine whether a single regional model can and should be used to estimate consumer response to price and nonprice programs and predict water use throughout a region, or whether multiple individual city demand models can and should be developed (i.e., rather than similar responses by consumers in the region, consumers in each city respond to the price and other conditions differently). Water demand predictions (forecasts of water use) and parameter estimates (consumer responses) of the Regional, Season Specific and City/Season Specific models are compared and evaluated for general applicability of water demand models and results. The overall predictability of the three models is compared via a likelihood ratio test to determine if one model is superior to the others. An alternative water demand model functional form is examined as a test of robustness and sensitivity of the analysis.

SUMMARY OF STATISTICAL MODELING RESULTS AND ANALYSIS

Three models of residential water demand were constructed and analyzed for the purpose of investigating the effectiveness of price and nonprice conservation programs. The water demand models were successfully tested using maximum likelihood regression techniques with information from the pooled 10-year time series, cross-sectional database. All three models were able to predict water demand with a high degree of accuracy and almost all of the coefficient estimates were statistically significant and had the expected demand relationship (summarized below). The models were also designed to ascertain whether the modeling results could be extended beyond the seven cities in the database for a more general statement about residential water use in the southwestern United States. This was not the case. Though all three models predict residential demand with a high degree of accuracy, the City/Season specific model was statistically a "better fit." However, this model lacks the generality and data variation to make statements about price and nonprice programs effectiveness beyond the scope of an individual city. That is, Los Angeles's nonprice water conservation programs have been effective in that city, but one can not say that such programs will be effective elsewhere. Although the Regional and Season Specific models were statistically not as close of a fit, the parameter relationships (coefficient values) estimated by each of the three models were very similar. The Season Specific model provides a compromise in statistical accuracy and generality of results, incorporating the broader range of parameter values considered (all cities) on a detailed seasonal basis.

Conservation Program Effectiveness and Water Demand Relationships

What are the general findings of the statistical modeling? Water price has a significant and negative impact on water use, but water demand is very price inelastic, more so than has been suggested in other studies. The highest elasticity estimate was for summer use (approximately -0.20). At this degree of consumer responsiveness water utilities could double their water rates and expect, at a maximum, only a 20 percent decrease in water use during the peak season. More likely, utilities should expect a water elasticity of -0.10 on an annual basis; a hefty 50 percent increase in rates will reduce use by 5 percent.

Statistical tests to determine whether consumers perceive and respond to marginal prices or average prices are inconclusive. Consumers appear to be responding to some combination of marginal and average prices. This makes it more difficult to design effective rate structures because it is not clear which price or prices consumers are responding to. This mixed consumer response is, in part, a result of the service charges prevalent in current rate structures. The use of fixed service charges with uniform or block rate structures results in declining average prices as consumption increases, even when marginal prices are rising. These results indicate that utilities interested in using price to encourage conservation should reexamine the incentives provided by their rate structures and, specifically, focus on reducing or even eliminating the fixed charge component.

Nonprice conservation programs appear to be effective if the water utility achieves a critical mass of programs. For Los Angeles, San Diego and Denver, the number of non-price programs have had the desired effect. For cities with fewer programs or relatively new experience with conservation programs, nonprice programs had no observable effect on demand. Conservation programs work independently of a drought environment, such as California's in the late 1980's and early 1990's and continue to work after the drought conditions have ceased. Conservation programs may be ultimately necessary simply to counteract an exogenous long-term increase in residential use.

Climate effects residential use in predictable ways. Water use is strongly correlated with average monthly temperature and seasonal variation in temperature. Precipitation was consistently insignificant in all models. All cities in this analysis are semi-arid to arid in climate and thus the ratio of evapotranspiration to precipitation is much greater than one. Landscape watering is necessary if one wants to maintain traditional residential lawns and trees. Random and infrequent rains do not change residential watering patterns to a significant degree. Other variables, exogenous to a water utility, such as residential income and the size of the city also vary but their influence is estimated to have a relative minor impact on residential use.

In summary, price and nonprice conservation programs are effective, but require a major commitment to implement. Consumers are very unresponsive to price increases under current rate structures, requiring large increases in price to achieve small reductions in demand. Nonprice conservation programs appear to be most effective when there are a substantial number of programs conducted over longer periods of time. Because the information regarding nonprice programs is incomplete, we are not able to distinguish the effectiveness of individual types or specific programs nor the residual or lasting effects of nonprice programs. Small changes in water rates or implementation of haphazard conservation programs will most likely not produce discernable results.

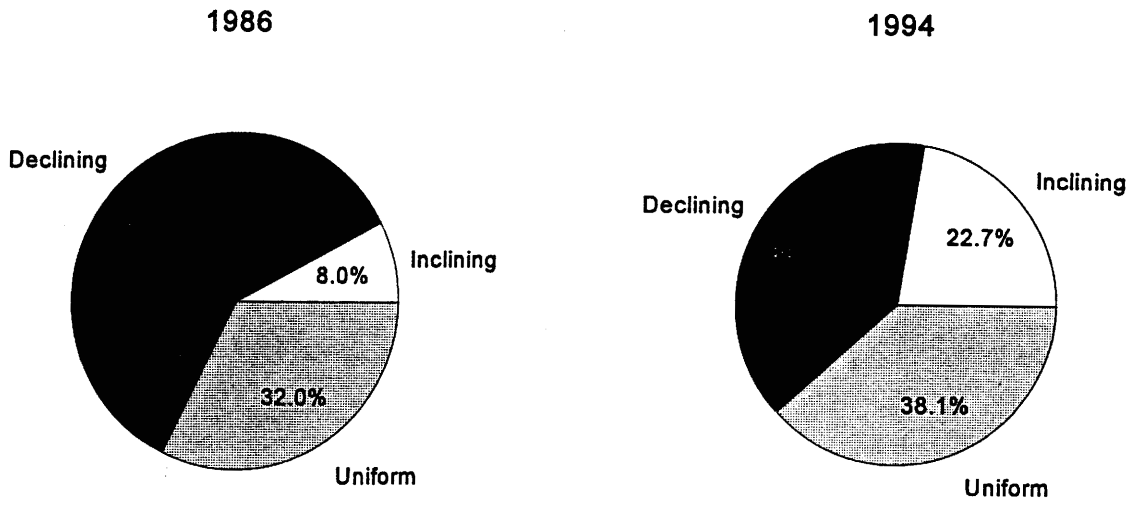
CHAPTER 1

IMPORTANCE AND TRENDS IN CONSERVATION PROGRAMS

Short-term recurrent drought and projected long-term demand-supply problems compel municipal water suppliers to consider water conservation measures. Conservation measures encourage consumers to use water more efficiently and reduce demand to meet the same needs. Conservation of water by itself is not the objective. Conservation induced reductions in individual and system-wide water demand can be used to alleviate temporary water shortages, avoid increased water supply, system expansion and consumer costs and extend the ability of existing supplies and system capacity to meet current and growing demands. A wide variety and number of conservation measures can be used in utility demand-side management programs. In general conservation measures can be classified as either price or nonprice programs.

Conservation price programs involve direct economic incentives for consumers to conserve through increases in price levels (cost) and/or conservation-oriented rate structures where consumer costs increase with the amount of water consumption. Although there have been increases in residential water prices in some areas, these are generally due to increases in supply, treatment and system costs rather than implemented as conservation incentives. This is in part due to revenue stability objectives and profit constraints faced by most public utilities. The result has been that in inflation adjusted terms price increases, if any, have been relatively small.

The move to conservation price programs is more evident in the number of utilities that have switched to some type of conservation-oriented rate structure. In 1986, approximately 60 percent of the nation's public water providers used declining residential rate structures that actually encourage water consumption (the more water a consumer uses the lower the price per unit). Over the past decade an increasing number of utilities have changed from declining block rate pricing to more conservation-oriented uniform and inclining rate structures where the price per unit remains the same or increases as water consumption increases. As illustrated in Figure 1.1, the move away from declining rate structures has been dramatic. By 1994 the number of water providers using declining rate structures was less than 40 percent, and the number of providers using inclining rate structures had increased from eight percent in 1986 to more than 22 percent. Three of the seven



Source: Ernst and Young, 1986 and 1994.
Figure 1.1 Changes in water rate structures in the United States

utilities in this study have changed their price and rate structures to conservation-oriented approaches.

Utilities nationwide are also using nonprice conservation programs as a substitute, or in addition, to price conservation programs in efforts to reduce residential demand. Examples of nonprice conservation programs include: public media messages and printed materials to increase public awareness and encourage conservation; school education programs; rebate and retrofit device programs to encourage installation of water efficient devices in existing homes; temporary ordinances that require consumers to reduce specific or overall water use during drought shortage situations; and permanent ordinances such as water efficient plumbing codes designed to reduce long-term water demand. Four of the seven utilities in this study have implemented from one to more than a dozen nonprice conservation programs over the period from 1984 through 1995.

RESEARCH NEEDS AND OBJECTIVES

Accurate information about consumer response to conservation programs is critical for selecting and implementing appropriate demand-side management strategies that will effectively encourage conservation in the long-term and that can be used to manage cyclical drought-induced supply shortages. Accurate knowledge about residential consumer's responses to conservation programs is also important in forecasting long-term demand, managing water supplies, determining acquisition requirements, formulating financial management decisions and for integrated resource management and planning. Utility managers need to know how residential water demand changes, that is how consumers perceive and respond to changes in prices and rate structures and to nonprice conservation measures. However, the effects of conservation programs such as multi-part tariffs and inclining or inverted block rate structures upon residential consumption in different regions are not well understood even though there is an extensive body of literature dealing with this issue. Further, the synergistic effects of price and nonprice programs are not well understood and there is very little literature dealing with this issue.

The purpose of this study is to build upon and extend previous water conservation research efforts to evaluate the effects of price and nonprice conservation programs on residential water demand in different urban areas of the southwestern United States. The main objectives of the study were to:

1. Collect residential water demand and conservation program information for selected study areas in southern California, Colorado and New Mexico and create a database and documentation of the data for use in this and future research. (Available as a separate research report.)
2. Analyze the data using statistical methods such as ANOVA, ARIMA, and regression to identify trends in water use, impacts of water conservation efforts, socioeconomic, and climatic related parameter changes.
3. To apply the revenue-consumption model developed at New Mexico State University to analyze the effectiveness of alternative rate structures on residential water savings in urban areas of southern California, Colorado and New Mexico. Following preliminary research this objective was subsequently revised to focus research on the development and analysis of more generally applicable water demand models.
4. Evaluate alternative models of water demand and develop a core model of water demand and conservation that can be broadly applied in different urban and regional areas.
5. Explore the interaction of weather, price and conservation programs in the context of a case study.

Another significant issue addressed by this study is the use and applicability of aggregate national and regional data in water demand studies. Do consumers in different cities actually respond similarly? And, is it appropriate and justified to use the results of conservation program effectiveness from another city? Many of the previous residential water demand studies assumed this to be the case and, because of the lack of more detailed information, used aggregate annual data. In addition, most of the previous studies examined relatively short periods of time. Aggregation of water demand information and the shorter time-periods considered limited the ability of previous researchers to determine consumer responses to important influences such as seasonal conditions and long-term responses to price and nonprice programs. This study examines both the appropriateness of regional aggregation in applying water demand models and long-term trends and relationships of residential water demand.

Econometric models of residential water demand are developed and applied to investigate the influences on water use and conservation program effectiveness in seven cities in three southwestern states over a 10-year period, from 1984 through mid-1995. This region was selected because it encompasses the greatest range of demand-supply problems in the United States and is the region most likely to experience exacerbation of these problems.

The water demand modeling techniques and results of this evaluation of the effectiveness of price and nonprice conservation programs are expected to benefit water utilities and consumers through lower costs and more secure water supplies resulting from improved understanding and better planning and implementation of residential price, rate structure and nonprice conservation programs.

REPORT ORGANIZATION

Chapter 2 introduces fundamental demand and rate structure concepts and terms used in this report, summarizes the contributions, approaches and limitations of previous water conservation research, describes the components and structure of the econometric water demand models and provides an overview of the research approach used in this study. Readers of this report are assumed to have a basic knowledge of economic concepts and statistics.

Chapter 3 provides background water demand information and summary statistics for each of the seven study areas. Adjustments to reported data are described and summary statistics are presented for: seasonal and study period water consumption, prices, rate structures, climate, socioeconomic conditions and utility nonprice conservation programs. Information necessary for evaluating the effectiveness of individual nonprice conservation programs and for more detailed analysis of consumer response to rate block pricing is identified. Almost universally, much of this information is not available, incomplete and/or is not reported or maintained on a consistent basis (see report recommendations) necessary for evaluation of programs. Information on the type and number of nonprice conservation programs is summarized in Chapter 3.

Chapter 4 presents the statistical results and evaluation of the Regional, Season Specific and City/Season Specific water demand models. Particular attention is given to evaluating consumer responsiveness to price (price elasticity), price perception, climate, drought, time and socioeconomic effects and the effectiveness of nonprice conservation programs. Different levels of data and model aggregation are examined for reliability and applicability of results to other situations. An alternative functional form of the water demand model is developed and used to test sensitivity and robustness of the results. Examples of water utility application of the price elasticity and nonprice conservation program estimates are also provided.

Chapter 5 provides a summary of the water demand model results and analysis of the effectiveness of price and nonprice programs and applicability of the results by water utility managers. Recommendations are made to increase the effectiveness and improve evaluation of future residential conservation programs.

CHAPTER 2

RESEARCH FRAMEWORK AND MODEL DEVELOPMENT

This chapter introduces fundamental demand and rate structure concepts and terms used in this report, summarizes the contributions, approaches and limitations of previous water conservation research and describes the econometric models and research framework used in this analysis. Readers of this report are assumed to have at least a basic knowledge of economic concepts and statistics.

FUNDAMENTAL CONCEPTS AND TERMS

Demand, Price and Elasticity

Evaluation of changes in residential water use and conservation policies implicitly or explicitly requires a model of consumer choice, that is, a model of water demand. Demand for a good can be measured by the quantity of the good individuals consume at various prices (costs). For normal goods it is assumed that the higher the price the lower the quantity demanded and vice versa. This inverse relationship between price and quantity is referred to as the "law of demand." In the case of water utilities, prices are established and consumers use this information to determine the quantity of water they want to consume (the price and total cost they will pay).

In general the quantity of water demanded by residential consumers is assumed to be influenced by the price of water, climate conditions, household income, number of people per household, number and efficiency of water using appliances and other factors. Demand models typically attempt to incorporate as many of these factors as is feasible. However, the availability of information and aggregation of information preclude the inclusion all of the factors and relationships that may influence demand. For example, information regarding residential water consumption and household income are usually only reported in aggregate form, either as total consumption or as average consumption and income per household. Average use per account does provide useful information about water demand, however, averages do not provide information about individual consumer's water demand responses. Individual account and household survey information are necessary to examine specific rather than average water demand relationships and programs affecting demand. Both the high cost of compiling and maintaining detailed account information (if available) and requirements or concerns about maintaining the confidentiality of information about an individual account and household place limits on the factors that can be considered.

A primary objective of this study is to investigate the effectiveness of price programs in achieving residential water conservation. In order to evaluate price program effectiveness we need to know how consumers are responding to changes in price. To investigate this question involves the use of demand models that describe the quantity of water that would be (is) consumed at various prices. Demand model information can then be used to estimate the price elasticity of demand for water.

The price elasticity of demand is a measure of consumer responsiveness of changes in the quantity of water consumed with changes in price. Price elasticity is reported in terms of the percentage change in the quantity demanded with a one percent change in the price of the good (% Δ Quantity / 1.0 %Δ Price). For example, a price elasticity of -0.5 indicates that for a one percent increase in price, the quantity demanded will decrease by a half of one percent or -0.5%. The negative sign is simply a result of the law of demand; as price goes up the quantity demanded goes down. The price elasticity of demand is characterized as: elastic - where a one percent increase in price will result in a greater than one percent decrease in the quantity consumed (e.g. -1.5); unitary elastic - where a one percent increase in price results in a one percent decrease in the quantity consumed (e.g. -1.0); and, inelastic - where a one percent increase in price results in a less than a one percent decrease in the quantity consumed (e.g. -0.5).

Previous research has found that residential demand for water is inelastic (with most studies estimating elasticity's ranging from around -0.25 to -0.70), indicating that consumers are relatively unresponsive to small changes in price. These findings are based for the most part on studies of utilities with small changes in real price, rate structures that did not encourage conservation, demand models that did not include effects of nonprice conservation programs and studies that examined relatively short periods of time. All of these are important factors in determining price elasticity and their exclusion in part or in whole may have resulted in over- or under estimating consumer response to conservation-oriented price programs. This study attempts to incorporate these and other factors by investigating water demand of utilities that have both changed price levels and implemented conservation-oriented rate structures and, by investigating monthly and seasonal consumer responses over longer periods of time.

Effect of Nonprice Conservation Programs on Demand

Nonprice conservation programs may also affect consumer's demand for water. Instead of using an increase in price to achieve a reductions in the quantity consumed, nonprice programs may influence consumer preferences so that they demand less at the same prices. Figure 2.1 illustrates a hypothetical situation where either a price conservation program or nonprice conservation program could be used to achieve the same reduction in the quantity of water consumed. Assuming that consumers are aware of and responsive to changes in price, by increasing the price (cost) per unit of water from P_1 to P_2, consumers with preferences shown by demand curve 1 choose to reduce their consumption from $Q_{W/O}$ to Q_{Price}. A similar reduction in use may also be achieved through nonprice programs that shift consumer demand (preferences) to the left from demand curve 1 to demand curve 2 (less is preferred at the same price). This shift may result from a change in consumer's preferences that have been influenced by conservation education programs, a reduction in use from

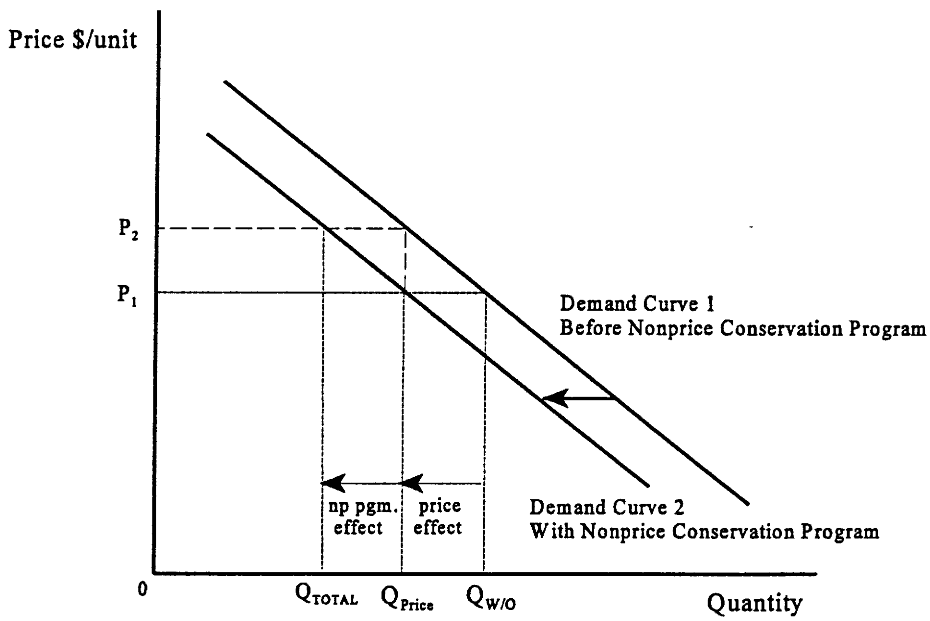


Figure 2.1 Price and nonprice program effects on demand

the installation of retrofit devices, mandatory use restrictions (emergency measures), or other programs that affect consumer behavior. The more inelastic or unresponsive consumers are to increases in price the steeper the demand curve, requiring larger increases in price to achieve relatively small decreases in demand. In this diagram, the combined effect of both price and nonprice programs results in a reduction in the quantity demanded to Q_{TOTAL}.

Supply Curves and Rate Structure

The supply curve shows the relationship between price (cost) and the various quantities of a good (water) that will be supplied. For most markets the supply curve for a good is increasing or upward sloping, that is the cost of providing additional quantities is increasing. For a variety of reasons, this is not always the situation for water providers where system supply costs may decline until higher costs of additional sources or capital/treatment capacity expansion increases system supply costs. Both the situation of declining incremental supply costs and rate structures implemented to achieve stable revenue streams has resulted in residential water supply curves (rate structures) that are not conservation-oriented or provide mixed signals to consumers regarding conservation.

A rate structure is the combination of fixed and variable fees charged for the supply of water. Fixed fees are independent of use levels and typically are in the form of service charges assessed each billing period regardless of the quantity consumed. Variable fees (rate per unit or marginal price, often called a consumption charge) are based on the amount a consumer uses, the quantity of water delivered by the utility to the consumer.

Four general types of price structure are predominantly employed by municipal water utilities: a uniform rate (the same rate/price for each unit consumed); declining rates (the greater the quantity used the lower the rate/price); inclining rate structures (the greater the quantity used the higher the rate/price); and seasonal rates (differential rates based on seasons). Inclining and declining rate structures are called tiered or block rate structures because different prices apply to different quantities (tiers) of water consumed. Theoretically, declining rate structures encourage higher water use because the cost or price of consuming each additional unit is less than the cost of the previous unit. Uniform, inclining, and seasonal rate structures, in theory, are more conservation-oriented than declining rate structures because consumers face the same or increasing prices for additional units

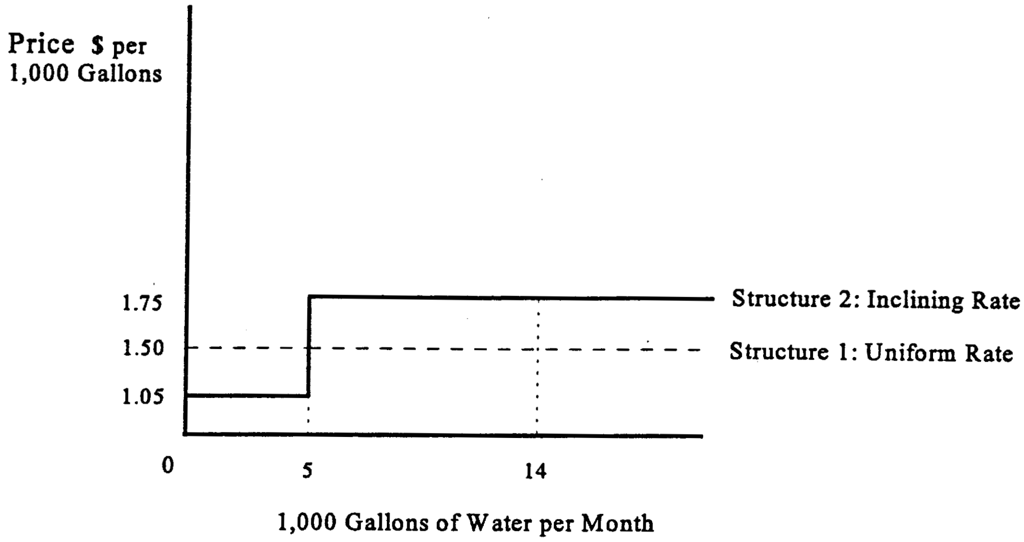


Figure 2.2 Example of uniform and inclining block rate structures

of water consumed. As shown earlier, water utilities are gradually moving away from declining rates and toward either uniform or inclining rate structures.

Examples of Rate Structures

An example of a uniform rate structure is illustrated in Figure 2.2. The horizontal axis represents the number of units of water (quantity), and the vertical axis represents the price per unit of water. With a uniform rate the supply curve (in strict terms not a supply curve but a rate structure) is a horizontal line (structure 1) where all units of water are priced at $1.50/unit, regardless of the quantity of water consumed. With an inclining (or declining) rate structure the price per unit depends on the quantity of water consumed. The term price block is used to specify the number of units (quantity) that can be purchased at a given price. Tiered rate structures may be composed of two or more price blocks. For example, consider rate structure 2 in Figure 2.2, representing a two-block inclining rate structure where the first 5,000 gallons of water are priced at $1.05/unit. Use greater than this level (second block) is priced at $1.75/unit. Because the cost per unit increases as consumption rises, increasing block rate structures should, at least in theory, encourage water conservation. Fixed or service charges in a rate structure and consumer awareness or perception of prices complicates both theory and empirical analysis of supply costs and consumer response. (In this example, the service charge element has been left out of rate structures 1 and 2.)

Marginal Price and Average Price

Price is often used loosely to mean either marginal price or average price. The specific meaning of price is important and depends on the particular use and context. Marginal price (MP) is defined as the price (cost) of the next unit of water consumed. Under the uniform rate, the marginal price is constant. In Figure 2.2, the marginal price is a $1.50 per thousand gallons. In a tiered block rate structure, marginal price is the price per unit for the relevant block which varies with the quantity of water consumed. For example, in Figure 2.2 the marginal price of water (price for the next unit consumed) for use below 5,000 gallons is $1.05 per thousand gallons. The marginal price for use greater than 5,000 is $1.75.

Average price (AP) is defined as the average per unit cost calculated by dividing the total cost of the quantity of water consumed (both fixed and variable charges) by the total number of units used (AP = total cost ÷ total quantity consumed). In the case of the uniform rate example above, the average price of water for 14,000 gallons of water is $1.50 per thousand gallons ($21.00 ÷ 14). Using the two-block inclining rate structure in Figure 2.2, again assuming no fixed or service charge, the average price of water when total water consumption for the month is 14,000 gallons is $1.50 per thousand gallons; calculated as the sum of the quantity consumed in the first block times the first block price per unit plus the sum of the quantity of water consumed in the second block times the second block price per unit (5 · $1.05 + 9 · $1.75 = $21.00; $21.00 ÷ 14 = $1.50).

In economic theory, consumers are assumed to respond to the marginal or incremental price for the next unit of water. However, whenever the cost per unit varies depending on the quantity of water consumed, as is the case with tiered rate structures and when there are fixed costs, the marginal (incremental) price and average price per unit for the total quantity of water consumed will differ, possibly sending mixed signals about price (cost) to consumers. In addition, consumer knowledge and perception of the per unit price may not reflect actual cost per unit or marginal prices because of limited information about the quantity of water consumed at any given point in time, the infrequency of water bills, their ex post nature (the total cost of consumption is only known after the fact) and often confusing billing information about water prices. As a result, some researchers have suggested that rather than using and responding to the marginal price of water, consumers instead may use the total bill amount (average price) as the basis for deciding how much water to consume.

Difficulty in understanding or obtaining accurate and timely information about the price for the next unit of water consumed is compounded by the additional cost of fixed fees or service charges assessed by most utilities. Monthly or billing period service charges are used by utilities to provide a more uniform revenue stream that does not vary with seasonal water demand. However, depending upon which price consumers respond to, fixed service charges can offset the conservation incentives of increasing marginal rates. This occurs because the average cost per unit of the fixed charge declines with increasing water consumption. This is illustrated in Figure 2.3 for a uniform rate structure. Similar to the uniform rate structure presented in Figure 2.2, the constant per unit rate of water is $1.50. However, the rate structure presented in Figure 2.3 also has a fixed service charge of $5.00. In this case the consumer pays a constant marginal price per unit but, because of the service charge, the average cost per unit is declining. Figure 2.4 illustrates the average cost and marginal cost for a two-block inclining rate structure with a service charge. As described in Figure 2.2 the first block price is $1.05 for use less than 5,000 gallons and $1.75 for use greater than 5,000 gallons. The fixed service charge is $5.00. Note that even though the price per unit increases for consumption beyond 5,000 gallons per month, the average price for all units consumed continues to decline with increasing consumption. Depending on the level of the marginal price, the average combined per unit cost of the fixed and marginal costs may actually be less than the marginal price in an inclining block rate structure.

A rate structure with increasing marginal prices while average price is declining sends mixed signals to consumers about their economic incentives to conserve water. This mixed incentive system creates problems in both understanding and analyzing consumer responses. Rate structures with any service charges, and in particular relatively large service charges in relation to the per unit cost and total water bill, are apt to create these mixed price signal conditions. Most water utilities, including those with inclining block rate structures, continue to use a service charge as part of their rate structure. Therefore, understanding which price(s) consumers perceive and which price(s) consumers respond to is critical in designing effective rate structures. This study, in addition to examining consumer response to price levels and structures, also examines consumer perceptions of price.

The availability of water use information dictates the evaluation methods and resolution of the analysis. Water utilities typically maintain records of total water use per billing period for their residential accounts. This aggregate information can be used to calculate average (per account)

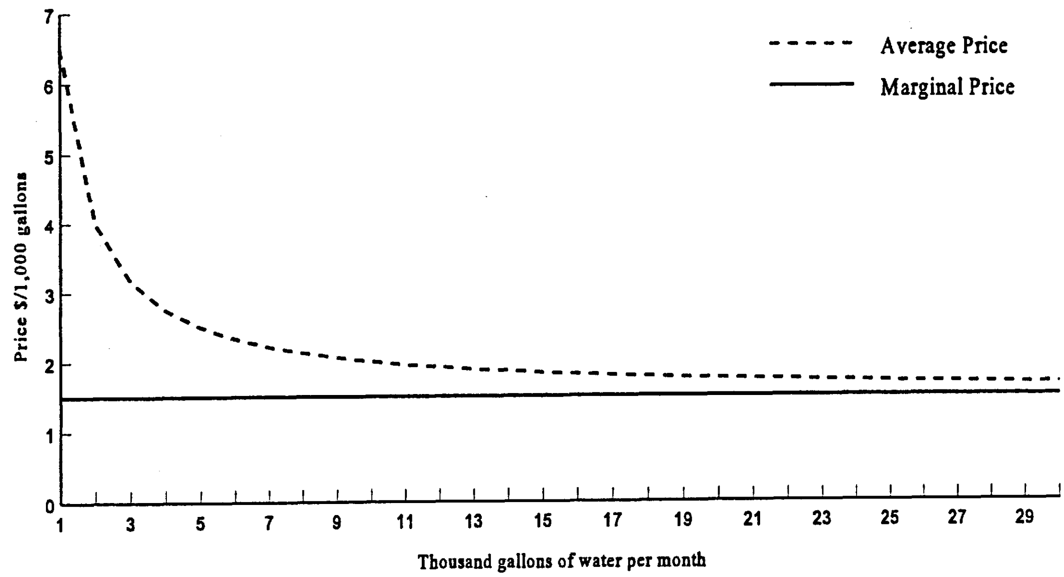


Figure 2.3 Average and marginal prices with a uniform rate and a service charge

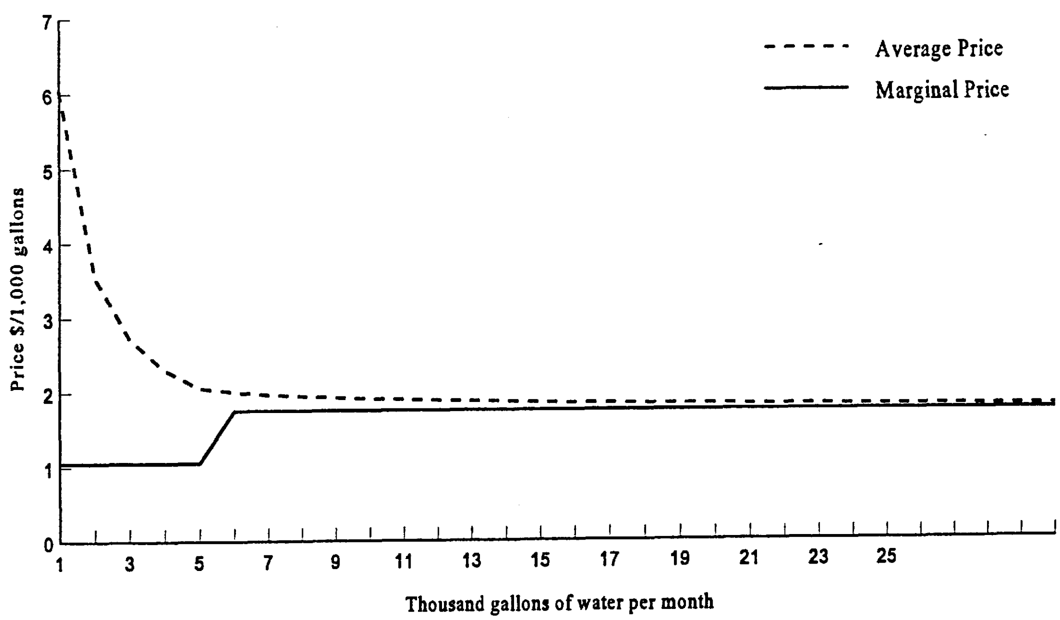


Figure 2.4 Average and marginal prices with a two-block inclining rate structure and a service charge

water use, average price (cost) and the marginal price for the average level of water use. Aggregate consumption information is not sufficient to determine the rate block distribution of consumers, that is, which rate blocks individual consumers are in. Individual account information is required to determine the number of consumers and quantity of water consumed in each rate block and substantial efforts were expended by the investigators of the research team to collect, develop and estimate the distribution of consumers by rate block. Unfortunately, water utilities compile this information on an infrequent basis, if at all, and consumption by rate block data is rarely available on a billing period basis which is necessary for more detailed analysis of consumer response to block rate structures and price levels. Because this information is not available, researchers instead must use the information that is available on total residential water consumption to derive average consumption and corresponding price levels. Again, the lack of rate block consumption information limits the ability of researchers and utility staff to evaluate actual consumer responses to price. This problem is compounded with increasing levels of aggregation, for example using annual consumption and billing data to evaluate consumer response to different rate structures, price levels and seasonal or monthly factors that influence demand.

Types of Statistical Models

Statistical models rely upon the variation in parameters to distinguish significant relationships. A lack of variation in parameter values increases the difficulty in identifying significant variable relationships or trends. For example, it is difficult to attribute changes in water demand to changes in price alone if the price in a given location only varies by a small amount, yet climate and other conditions vary by large amounts. Different types of models are used to increase the observed variation in parameters and extend the applications of models and results. Cross-sectional and time series are two types of models that are used to enhance parameter variation and study trends and differences across groups of observations and time.

Cross-sectional models use observations from a number of different groups at a given point in time. The use of observations from more than one group increases the variation in parameters providing additional information on variable relationships and the statistical significance of the relationships. This research investigates the use of cross-sectional (regional) models of water demand in seven different cities. Critical requirements are that the parameters of each group must have the same meaning (definition and measure must be the same) and the different groups must have the same fundamental relationships (e.g. demand is a function of the same variables). Another requirement is that variance in data series must be statistically equal (homoscedastic). If these conditions are not met, it is not valid to combine the data from the different groups in the same model and the model results of combining the groups may not be accurate or reliable.

Time series models use observations over a number of periods of time to evaluate patterns and trends. The use of observations from more than one period of time captures the variation and trends in parameters that are changing over time and also changing in response to variations in other conditions. Cross-sectional models by themselves do not capture these time related relationships. A common statistical problem associated with either time series and cross-sectional models is called autocorrelation, the correlation between individual observations. Statistical techniques can be applied to test for the existence of, and correct for some types of autocorrelation. If left uncorrected, autocorrelation will lead to results that may not be accurate or reliable.

Time series-cross-sectional (TSCS) models pool both time series and cross-sectional data to further increase the observed variation in parameters, test for general applicability of the model and to extend the results to other similar situations. This study uses times series monthly models for individual cities over a 10-year period and combined time series, cross-sectional models to analyze water demand relationships, trends and consumer responses to price and nonprice conservation programs.

PREVIOUS RESEARCH

Econometric estimation of water demand has almost entirely focused upon residential and municipal demand. Residential water demand studies and forecasts have progressed from straightforward models that sum per capita consumption to econometric estimation of price-quantity relationships. Theory and prior empirical water demand studies postulate that the quantity of water demanded varies with the "appropriate price" of water, income of consumers, climate, conservation policies and other factors. Table 2.1 summarizes a number of these studies identifying the type of model(s), level of aggregation and time period of observations, model formulation and price elasticity estimates.

The water demand estimation studies in Table 2.1 are grouped based on the level of aggregation; studies that use utility-wide annual or monthly aggregate water use data and those that use household level water consumption data. Generally, the period of time and scope of water demand estimation studies are limited because of the lack of availability or uniformity of information or, when available, the time-consuming and costly task of data collection.

Several widely cited studies have used highly aggregated data, such as annual water demand statistics, to analyze and reach conclusions regarding water demand relationships and consumer price response [Foster and Beattie (1979); Thomas and Syme (1988); and Young (1973)]. A common limitation of these studies stems from the use of annual and regionally aggregated data. As discussed in more detail below and in the conclusions of this study, aggregation of observations can be statistically problematic and such data is unable to offer insight into seasonal fluctuations in water demand or allow for comparisons in monthly use from year to year. The use of annual aggregate data also prohibits investigation into how individual factors, such as low precipitation and high temperatures, influence water demand in a given season within a city or across a region.

Many of the previous studies consider water demand relationships and changes over relatively short periods of time. This prevents these studies from evaluating long-term relationships and changes in demand and in the case of aggregate annual data, from evaluating seasonal water demand relationships. Of the studies listed in Table 2.1, those that have examined water demand of utilities across regions or the nation seldom span beyond a single year.

Long-term effects are particularly important because it takes time for consumers to respond to changes in rate structures and behavioral nonprice conservation programs. Another important aspect is that for many goods, long-term consumer price elasticity is higher (more elastic) than short-term price elasticity.

Our research addresses consumer responses in the long-run by drawing upon monthly observations in seven cities in three southwestern states over a time period of more than 10 years. This permits investigation of long-term water demand conditions and consumer responses. As noted earlier, a variety of rate structures, nonprice conservation programs, demographic and climatological factors are represented in this study, both across cities and over time. The increased variation in the water demand information included in this study should also help to identify significant water

Table 2.1

Previous water demand estimation studies

Author	Data Type	Data Area	Study Period	Model	Elasticity
AGGREGATE DATA					
Agthe, Billings, Dobra and Raffiee (1986)	time series monthly	Tucson, AZ	1974-80		
marginal price				linear	LR - 0.624
rate premium				linear	LR - 0.247
Billings and Agthe (1980)	time series monthly	Tucson, AZ	1974-77		
marginal price				double log	- 0.39
rate premium				linear	- 0.63
Billings and Day (1989)	pooled monthly	southern Arizona utilities	1974-80		
marginal price and rate premium				linear	- 0.52
average price				linear	- 0.70
Foster and Beattie (1979)	cross-sectional annual	218 U.S. cities (AWWA survey)	1960	price exponential	
average price (southwest US)					- 0.12
Nieswiadomy (1992)	cross-sectional annual	430 U.S. utilities (AWWA survey)	1984		
marginal price (south region of U.S.)				double log	- 0.17
average price (south region of U.S.)				double log	- 0.60
Shin test - ap/mp (south region of U.S.)				double log	- 0.40
Young (1973)	time series annual	Municipal water in Tucson, AZ	1946-64	linear	- 0.65
average price				logarithmic	- 0.60
			1965-71	linear	- 0.41
				logarithmic	- 0.41
HOUSEHOLD DATA					
Chicoine, Deller, Ramamurthy (1986)	pooled monthly	54 households from 9 rural Illinois water districts	1984	linear	
marginal price					- 0.42
second price (AP - MP)					- 0.27
Danielson (1979)	pooled monthly	261 households in Raleigh, NC	1969-74	double log	
marginal price total residential demand					- 0.272
marginal price winter demand					- 0.305
marginal price sprinkling demand					- 1.38
Howe (1982)	pooled daily	39 areas from 16 U.S. utilities John Hopkins University data set	1963-65	linear	
marginal price winter (east & west regions)					- 0.06
marginal price summer use (east)					- 0.568
marginal price summer (west)					- 0.427

demand factors and relationships. Furthermore, most previous studies only estimated short-run elasticity, annual aggregate elasticity and/or elasticity for a single city with small changes in price. This study investigates long-run demand elasticity based on ten years of monthly/seasonal observations for seven cities for a variety of rate structures and price levels.

Price is assumed to be an important factor in water demand and almost all studies report that, to varying degrees, residential water demand is price inelastic. Accurate information about how inelastic demand is in general, seasonally and in the long-term is very important in designing effective water conservation programs. However, what price to use and how to incorporate price into water demand models remains an issue that directly impacts the analysis results. Consumer demand has been estimated utilizing ex post calculated average price [Young (1973); Foster and Beattie (1979); Billings and Day (1989); Nieswiadomy (1992)], marginal price [Danielson (1979); Thomas and Syme (1988); Nieswiadomy and Molina (1991); Nieswiadomy (1992)], and a combination of marginal price and the rate premium (difference variable) [Billings and Agthe (1980); Billings (1982); Howe (1982); Agthe, Billings, Dobra and Raffiee (1986); Chicoine, Deller and Ramamurthy (1986); Billings and Day (1989)]. Inclusion of each of these variables has proven problematic.

Average price, calculated as the total bill divided by the number of units of water used per billing period, is endogenous to quantity by definition. Taylor (1975) suggests a technique that allows this obstacle to be avoided. Taylor's method employs the incorporation of fixed use levels and corresponding prices for such levels based on the employed rate structure.

To address the stair step nature of block rate prices some researchers have suggested the use of a difference term [$(d = (MP_1 - MP_2) \cdot Q_1)$] to capture the income effect on demand from step changes in price. Many other researchers believe this effect to be negligible and do not include a difference term. This latter argument is supported by Foster and Beattie (1981); Howe (1982); and Chicoine, Deller and Ramamurthy (1986). These researchers further state that, because water bills represent a small proportion of total household expenses and rate structures and bill statements typically are complex, customers may not be reacting to the difference variable but instead to some measure of average price.

Taylor (1975), studying demand for electricity, suggested that, under the block-rate pricing scheme, the explanatory variables should include marginal and average price. Taylor points out that using only the average price defined as an ex post ratio of total expenditure to quantity consumed can yield a negative dependence between use and price that reflects nothing more than arithmetic. On the other hand, as Taylor also notes, using only the marginal price as "the" price, while having strong theoretical appeal, conveys only part of the story. A single marginal price "is relevant to a consumer's decision only when he is consuming in the block to which it is attached; it governs behavior while the consumer is in that block, but it does not, in and of itself, determine why he consumes in that block as opposed to some other block" (pg. 78). Within this water demand study, marginal price and average price are represented in the Shin (1985) price perception model (as shown below).

AMBIGUITIES OF RATE STRUCTURE COMPONENTS

If you assume that consumers are unaware of precise rate structure information, it is then plausible that certain rate components relay an inaccurate message to consumers. Nieswiadomy and Molina (1991) discuss how the service charge element of the rate structure may directly influence consumer price perception under an inclining rate structure. They state that consumers who face a relatively small service charge and base their marginal price calculations on monthly statements may underestimate the true marginal rate of water. This miscalculation may result in consumers using larger quantities of a good they view to be inexpensive. The researchers further state that consumers who face a relatively large service charge and perform the same calculation may overestimate the true marginal rate of water. This error may cause consumers to lower their use levels because they view the price of water to be too costly. This highlights the importance of designing a rate structure that sends appropriate price signals to consumers, developing consumer awareness of rate structures and understanding consumer perceptions of and responses to established and proposed rate structures.

SHIN'S PRICE PERCEPTION MODEL

An approach used to address the issue of consumer price perception is Shin's (1985) model, which tests whether consumers respond to average price, marginal price, or a combination of the two. The basic concept underlying the Shin model is that it is difficult for consumers to determine the actual rate schedule. There are several reasons for this. First, it is difficult to determine one's water use during the month because water meters are generally difficult to read. This makes it difficult for the consumer to know when they have switched from one block to another. A second difficulty faced by water consumers is the inclusion of a sewage charge in their water bill, which may or may not be shown separately. With combined billing statements, the consumer may also confuse the sanitation (solid waste) charge with the sewage charge. Another factor that complicates understanding of water supply prices is how the sewage fee is determined. Many utilities determine the monthly sewage charge based on winter water consumption. Consumers may or may not be aware of this circumstance but it may effect their monthly bill and response to water supply rate structures.

If the benefits of learning the true nature of the rate schedule are less than the costs, it is likely that the consumer will react to some proxy of marginal price, such as an ex post calculated average price from a recent bill. If the costs of learning the true nature of the rate schedule are low, it may be that the consumer reacts to the true marginal price. In order to incorporate a number of possible price response situations, Shin uses perceived price, P^*, as the price variable where this price variable is defined ex ante as:

$$P^* = MP \cdot (AP/MP)^k \tag{2.1}$$

where k is a parameter to be estimated along with the other parameters in the specified water demand relationship. If, given the data used, k is shown not to be significantly different from zero then, ex post, $P^* = MP$ and consumers in the data set as a whole are said to be responding to marginal price. If, on the other hand, k is shown not to be significantly different from one, then $P^* = AP$ and consumers respond to average price.

Climate and Income Parameters

It is expected that residential water use is influenced by temperature (positive relationship) and precipitation (inverse relationship). Foster and Beattie (1979) demonstrate that regions with significant rainfall (greater than 26 inches: New England, Northern Atlantic, Midwestern and Southern United States) exhibit low irrigation demand (outdoor use). In these regions, in-house use comprises a large portion of total demand. In regions with low rainfall levels (13 inches: Plains and Rocky Mountains, Southwestern and Northern California and Pacific Northwestern United States), irrigation demand is high and outdoor use is a larger percentage of total residential demand. Using annual, cross-sectional data for 1960 (AWWA survey), Foster and Beattie found that regions with greater precipitation exhibit lower elasticities (-0.097), while regions with lower precipitation levels have higher overall elasticity estimates (-0.205).

Nieswiadomy (1992) also investigated the regional impacts of weather conditions. Utilizing a national data set for the year 1984 (AWWA survey) he explores the impacts temperature and precipitation have on annual water demand in the north central, northeast, south and west regions of the United States. Rainfall is measured as the average monthly rainfall for months between the last spring freeze month and the first fall freeze month; temperature is measured as the average temperature for months between last spring freeze month and first fall freeze month. Incorporating the Shin price perception formulation, Nieswiadomy's results indicate that average rainfall significantly impacts annual water use (inverse relationship) in the southern region of the United States and average temperature significantly impacts annual water use (positively) in the north central, southern and western regions of the United States.

A common representation of weather in demand estimation is the use of evapotranspiration adjusted for rainfall [Agthe, Billings, Dobra and Raffiee (1986); Agthe and Billings (1980); Billings (1982)]. Other representations of weather include: annual rainfall [Young (1973)]; summer and winter rain, monthly temperature and monthly high temperature [Billings and Day (1989)]; and average annual precipitation and temperature [Stevens, Miller and Willis (1992)].

Because of the lack of availability of more detailed information, a significant number of previous studies were limited to using annual consumption and climate data which fail to capture seasonal variations in consumption and seasonal rate structures. The monthly observations in this analysis enable climate conditions to be represented by monthly and seasonal average temperatures measured in degrees Fahrenheit and total monthly and seasonal precipitation measured in inches.

Household income is expected to have a positive impact on water demand as shown by Foster and Beattie (1979); Agthe, Billings, Dobra and Raffiee (1986); Agthe and Billings (1980); Billings (1982); Chicoine, Deller and Ramamurthy (1986); Nieswiadomy (1992); and Stevens, Miller and Willis (1992). In this analysis, median per capita income, adjusted for inflation, is used as the income parameter in the water demand models [Foster and Beattie (1979)]. The use of median income is a reflection of data availability and is consistent with the level of detail of water consumption observations.

Effects of Nonprice Conservation Programs

Relatively few studies have explored the effects of nonprice conservation programs on single-family residential water demand. Of those that have, almost all examine a single program (e.g. distribution of plumbing retrofit devices or public awareness of media campaigns) for a short period of time in isolation of other demand factors and trends and/or do not distinguish between the presence of one conservation program versus several concurrent or different types of programs [e.g. Bauman and Opitz (1993); Kiefer (1993); Testa and Newton (1993); Anderson-Rodriguez and Aston (1993); Feguson and Whitney (1993)]. To date, representation of nonprice conservation programs in water demand models has been restricted to binary variables simply because data necessary for a more detailed examination is seldom documented or available for analysis. This is a continuing problem that will not be resolved until more detailed and consistent information about nonprice program efforts are developed and maintained.

Nieswiadomy (1992) analyzes how the presence or absence of any conservation program and presence or absence of public education programs influences household use levels. His analysis uses 1984 annual AWWA survey data from United States water utilities serving populations greater than 10,000. A dummy variable representing any conservation program and another dummy for public information programs were included in three forms of double-log estimation equations for four regions of the United States (a model using AP, a model using MP and Shin's combined AP/MP price perception model). In Nieswiadomy's study, public education programs were statistically significant in influencing water demand in the western region of the United States under the average price model and the price perception model, while overall conservation programs were statistically insignificant under each of the three models in all regions of the United States.

The impacts of community-wide water conservation messages voiced by institutions other than area water utilities (though widely promoted) has received little attention. Billings and Day (1989) included a weighted publicity index representing the number of newspaper articles printed in a leading area paper during the study period. The "publicity elasticity" for the average price and marginal price models averaged -0.05.

Some researchers [Palmini and Shelton (1982) and Cameron and Wright (1990)] feel both private and public benefits must be emphasized for nonprice conservation programs to be effective. For example, water conservation offers individual economic benefits from energy and water savings made possible by retrofit devices (i.e., toilet dams, faucet restrictors, low-flow shower heads) and public benefits, such as extending water supplies into the future. Because water bills account for such a small percentage of household income, emphasis of public benefits may inspire more water conservation efforts at the household level than highlighting private benefits.

This study examines the impact of nonprice conservation programs through the inclusion of a continuous variable, which represents the level of effort of individual cities, (i.e., the number of active programs on a monthly basis) included in the analysis. Additional information on the types and number of nonprice conservation programs is provided in Chapter 3.

Synergistic Effects of Price and Nonprice Programs

Varying schools of thought emerge from past research in regard to the synergistic effects of price and nonprice conservation programs. Some researchers contend that reductions in water use will only occur in the face of significant price increases [Cameron and Wright, (1990) and Martin and Kulakowski, (1991)]. Martin and Kulakowski (1991, p.166) note that "...nominal water price would have to be raised by the rate of inflation plus approximately the rate of change in real income each year just to maintain constant rather than increasing water use," and "If reduced use is desired in an environment where per capita incomes are expanding, it will be necessary to increase real prices 'significantly' in order to overcome the income effects."

Others investigators believe that the combination of price and nonprice programs achieves the goal of water conservation more effectively. Martin (1984) states that major decreases in water use per capita occur only where a major price increase is accompanied by major public awareness of the action surrounding the passage of the increase in the price schedule. Moncur (1987) claims that the presence of nonprice programs enhances the price elasticity, thus lowering the price increase necessary to induce the desired reduction in water use. Empirical evidence for these opinions is not provided.

It is difficult to deduce the synergistic effects of price and nonprice programs and there is little evidence to support claims because the information essential for an accurate assessment is typically not available. Although specific water pricing data is documented by water utilities, information about nonprice conservation programs is often not recorded in any detail or degree of consistency. As part of this analysis, efforts were made to collect and compile specific and consistent information on all nonprice conservation programs implemented in each of the study areas on a monthly basis over a 10-year period.

The water demand models in this study incorporate a continuous nonprice conservation variable constructed to represent the breadth of conservation programs in effect on a monthly basis. This method provides a measure of the number of individual programs employed on a monthly basis throughout the time period of the study, allowing the distinction between study areas with numerous programs and areas with only a few, or none at all. Although this methodology assumes that all programs and all levels of commitment per program are identical, there was insufficient data to separate out alternative program effects.

SPECIFICATION OF RESIDENTIAL WATER DEMAND MODELS

In this section, three different water demand models used by this study to evaluate consumer response and effectiveness of price and nonprice conservation programs are developed and the individual parameters specified. Econometric analysis of the models includes testing the assumption that information from different cities can be aggregated into a regional demand model. Models are also developed to examine seasonal variation in water demand on a regional and individual city basis. As noted below, each water demand model has advantages and disadvantages. Following development of the models in this section and chapter, the study area characteristics and parameter values that are used in the analysis are presented in Chapter 3. The empirical results, comparison and application of the water demand models are presented in Chapter 4.

The quantity of water demanded by residential consumers is assumed to be influenced by the price of water, climate conditions, household income and other factors. Consumer water demand behavior can be described by a constant elasticity demand function of the general form shown by equation 2.2 [Nieswiadomy (1992); Shin (1985); Foster and Beattie (1979)]:

$$q = A/P^b \qquad (2.2)$$

where A is a combined factor incorporating other influences on water use (such as temperature and precipitation), P is the perceived price of water, and b is the estimated elasticity.

Following Shin (1985), we assume that individual consumer price perception is some combination of average and marginal price as follows:

$$P = MP \cdot (AP/MP)^k \tag{2.3}$$

where P is the price perceived (and responded to) by the consumer; MP is the actual marginal price; and AP/MP is the ratio of average price to marginal price (a single variable). Substituting equation 2.3 into 2.2 results in:

$$q = A[\, MP^{-b} \cdot (AP/MP)^{-bk}] \tag{2.4}$$

The coefficient b is an exponent for two variables (MP and AP/MP), but the exponents differ by k. In the formulated regression equation, b is represented by the coefficient, b_1 and bk by the coefficient b_2. Then k is determined as:

$$k = b_2/b_1. \tag{2.5}$$

Nonprice effects such as temperature (*TEMP*), precipitation (*PREC*), and income (*INC*) are assumed to shift demand but not change elasticity. These variables shift the constant value, A, in equation 2.2. Two other variables may also shift demand: (1) consumer knowledge of the drought taking place in southern California during the early 1990's may have had a restrictive effect on demand and (2) consumer behavior over the long-term (*time*) may change independent of other factors included in the model. The water demand model is applied to citywide data requiring a variable for the number of accounts, (*ACCT*). A complimentary good to water consumption is sewer service. In most cities examined in this study, sewer rates are based on winter consumption levels. In essence, the sewer charge is fixed for the rest of the year and is not a variable in demand. Incorporating the outlined variables into the model results in the following equation:

$$Q_t = b \cdot MP^{-b1} \cdot (AP/MP)^{b2} \cdot INC^{b3} \cdot TEMP^{b4} \cdot PREC^{b5} \cdot ACCT^{b6} \cdot CONS^{b7} \cdot Drought^{b8} \cdot Time^{b9} \quad (2.6)$$

To estimate equation 2.6, conversion to a linear form is required (logarithmic transformation indicated by ln). The actual estimation equation is as follows:

$$\ln (Q_t) = b_0 + b_1 \ln (MP_t) + b_2 \ln (AP/MP_t) + b_3 \ln (INC_t) + b_4 \ln (TEMP_t) +$$
$$b_5 \ln (PREC_t) + b_6 \ln (ACCT_t) + b_7 (CONS_t) + b_8 (Drought_t) + b_9 (Time_t) + M \quad (2.7)$$

The following is a list of variable names and definitions (all monetary values are in constant dollars):

1. Q_t = total city monthly residential water quantity consumed at time *t*;
2. Mp_t = marginal price per 1,000 gallons; the marginal price appropriate for the average quantity consumed for the city for that month;
3. AP/MP_t = ratio of average price to marginal price; monthly total single-family residential revenue divided by total single-family residential monthly water use for that city;
4. INC_t = monthly average household income for that city;
5. $TEMP_t$ = average monthly temperature in degrees Fahrenheit;
6. $PREC_t$ = total monthly precipitation in inches;
7. $ACCT_t$ = number of single-family residential accounts for that month and city;
8. *CONS* = number of nonprice conservation programs in effect;
9. *Drought* = binary variable for drought conditions in southern California during January 1991 through March 1993;
10. *Time* = time, year and month on a fractional year basis;
11. *M* = normally distributed error;
12. b1 .. b9 are coefficients to be estimated. Referred to as "betas;"
13. t = time period of variable observation

AGGREGATION

An important part of this research is an analysis of the differences and similarities of individual city water demands in the study area. More specifically: Are the parameter relationships of the demand model (betas) the same for cities in the region or do they change across observational units, either across cities or over time? The most general model of demand is estimated on a time-series, cross-sectional database. Because the cross-section consists of water demand for a number of cities in the southwestern United States this model is referred to as the Regional model in this study. There are several advantages and reasons for using a TSCS (regional) model:

- The Regional model is conceptually the simplest (one model fits all) and the findings can be extended to other southwestern cities. This means that the estimated coefficients of demand factors in the Regional model are the same for different cities and over time (i.e., demand elasticity for water remains constant between cities and over an extended period of time - this assumption is critically examined in the Season Specific and City/Season Specific models).
- Because water rates in individual cities, when measured in real terms, do not vary significantly from year to year, a cross-sectional model is necessary to capture a broad representation and variation in consumer response to a variety of rate structures.
- Time series data is more likely to capture the cumulative effects of nonprice conservation programs, long-term water demand price elasticity and other water demand influences.

However, the Regional model may *not* be appropriate for urban water demand estimation in all cities throughout the southwestern United States. The implicit assumption in a regional model is that residential water users have similar habits over time and between cities (this does not mean that water use is constant over cities, as many other factors such as rate structures, climate, income and conservation programs also influence water use levels). If this assumption is inappropriate (this can be accurately determined through statistical tests) then a more specific formulation of the demand model should be used which allows for coefficient changes over time and/or between cities.

Therefore, two other water demand models that are more specific (lower levels of aggregation than the regional model) are also developed and evaluated in this analysis.

SEASON SPECIFIC AND CITY/SEASON SPECIFIC MODELS

Rather than remaining constant, the demand relationships represented in the regional model (equation 2.6) may change over time, particularly from season to season. Although the temperature variable may account for most of the annual cycle of demand, as the primary uses of water changes from season to season, the price elasticity or responsiveness of consumers may also vary between seasons. We employ two additional models to help determine whether the general regional model is adequate to predict seasonal differences in consumer demand:

- The **Season Specific** model is a time series, cross-sectional regional model incorporating seasonal water demand parameters with observations disaggregated into four seasons. In the Season Specific model the relationships of seasonal water demands across cities and consumer responses to seasonal water prices can be estimated. This provides a method to investigate seasonal variations in water demand influences such as different summer, winter, spring and fall price elasticities of demand. Again, if cross-sectional aggregation of cities is appropriate, that is consumers in different cities respond similarly across the region, then the results of the seasonal model can be compared with the more general Regional model to investigate seasonal versus annual demand relationships.
- The **City/Season Specific** model is a time series model that incorporates seasonal demand parameters for each individual city. A separate *MP* and *AP/MP* price variable is defined for each season for each city (56 price variables in total). These estimated coefficients of the City/Season Specific model represent only the water demand relationship for each individual city. Because the individual parameter coefficient estimates are restricted to the observations for an individual city and season, there may be improvements in the predictive results of the City/Season Specific model for individual cities. However, there are several disadvantages of the City/Season Specific model associated with the reduced scope and observations.

The City/Season Specific model is the least general of the three models and this restricts the applicability of its results to a specific city rather than to other locations and water demand situations. Another disadvantage of the City/Season Specific model is that predictions for changes in variables outside of the range of values historically observed for that particular city (the values that are used to parameterize the model estimates) will be unreliable. For example, a City/Season Specific model parameterized for the City of Denver with historical data may accurately predict water use in Denver. However, if we were to substitute historical data with that of a hypothetical pricing scheme (e.g.. a change in the water rate structure), the model would be less reliable in predicting Denver's water use. Similarly, if *any* rate structure data that was a significant departure from Denver's current rates were incorporated into the modeling database, the model would be unable to predict Denver's response to such a rate structure with any level of accuracy. Also, conclusions regarding price and nonprice conservation programs derived from a City/Season Specific model are even more problematic when applied to cities outside the city specific study area.

RESEARCH OBJECTIVES AND PROCEDURE

This section provides an overview of the research objectives and research procedures of this study. The overall purpose of this study is develop information and evaluate and compare the effects of price and nonprice conservation programs on residential consumption in different urban areas of the southwestern United States. The four main objectives of this study are to:

1. Collect, enter into a database and document water demand information for selected regions in Southern California, Colorado and New Mexico
2. Analyze the data using statistical methods to identify trends in water use, impacts of water conservation efforts, socioeconomic, and climatic related parameter changes
3. Develop and evaluate alternative models of water demand including a core model of water demand and conservation that can be broadly applied in different urban and regional areas
4. Explore the interaction of weather, price and conservation programs

The following five steps summarize the research procedures applied to accomplish the objectives of this study:

- **Review Previous Literature and Develop Water Demand Models.** Previous water demand estimation study methods, advances and limitation were reviewed and, building upon and extending this research, three water demand models are developed to investigate consumer response to price and nonprice conservation programs and other factors that may influence demand. The first model (Regional) assumes that consumers in different cities respond similarly across the region and throughout the year to rate structures, price levels, nonprice conservation programs, climate, income and other factors. The second model (Season Specific) is designed to investigate seasonal variations in consumer response across the region to changes in rate structures, price levels, nonprice conservation programs, climate, income and other factors. The third model (City/Season Specific) is designed to investigate individual city and seasonal variations in consumer response to rate structures, price levels, nonprice conservation programs, climate, income and other factors. The design and evaluation of each of the water demand models requires consideration of the type, level of detail and quality of water demand information available.
- **Select the Study Areas and Identify and Collect the Information Required for the Water Demand Models and Analysis.** Study areas were selected and with the cooperation of seven water utilities in three southwestern states, information on residential water consumption, rate structures, revenue and nonprice conservation programs covering the period from 1980 through mid-1995 was collected as available. The study area cities are: Los Angeles and San Diego, California; Broomfield and Denver, Colorado; and Albuquerque, Las Cruces and Santa Fe, New Mexico. Data collected and developed for this research is grouped into four major categories:

  1) utility data
  2) climatological data
  3) socioeconomic data and
  4) nonprice conservation program information

Study area characteristics, and specifics regarding data gathered and sources of information are described in detail in Chapter 3.

- **Develop, Refine and Document the Residential Water Demand Database.** An electronic database of the residential water demand information collected was created and consistent series of observations for all of the water demand variables for each study area were developed and refined. Reporting periods and units of measurement of consumption, price and other data varied both within and across cities over the period of study. Computational adjustments were required to develop a consistent data series of monthly observations and to verify and correct anomalies in reported data. The data gathered for this research and data development and adjustment procedures are described in detail in a separate report entitled *Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database* (1997). A copy of this report may be obtained through the American Water Works Association Research Foundation (Denver, Colorado) and The Powell Consortium Water Resource Research Institutes (contact: Wyoming Water Resource Center, University of Wyoming, Laramie, Wyoming; or New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces, New Mexico). Summary statistics of residential water consumption, rate structures, price levels, climate, socioeconomic and nonprice water conservation program information by study area are presented in Chapter 3 of this report. Although data was collected for the period from 1980 through mid-1995, data sufficient for modeling purposes was only available for the time period of January 1984 to mid-1995.

- **Water Demand Model Estimation and Analysis.** Each of the three water demand models are tested, refined and analyzed using the pooled 10-year time series, cross-sectional database developed for the seven study areas. Time series and cross-sectional statistical tests and corrections for autocorrelation and heteroscedasticity are made as necessary. The results of each of the models are reported and coefficient values are analyzed for statistical significance, theoretical consistency and magnitude. Price variable coefficients are analyzed for effect on water demand (responsiveness) and consumer recognition of conservation pricing programs is explored. The issue of consumer recognition and perception of price programs involves the questions: Are consumers responding to the average price of water consumed? Or, as is assumed by proponents of conservation and increasing block-rate-price structures, Are consumers perceiving and responding to the marginal price of the next unit of water in an increasing block rate structure by lowering their use? In addition to consumer response to price programs, nonprice conservation programs are evaluated for overall significance and effect on water demand. The results of the models are also examined to identify relationships and trends in regional and city specific water demand.

- **Evaluation of Regional Applicability and Comparison of Water Demand Models Predictions.** Results of the Regional, Season Specific and City/Season Specific models are evaluated and tests are conducted to determine whether one regional model can and should be used to estimate consumer response to price and nonprice programs and predict water use throughout a region, or whether multiple individual city demand models can and should be developed (i.e., rather than similar responses by consumers in the region, consumers in each city respond to the price and other conditions differently). Water demand predictions (forecasts of water use) and parameter estimates (consumer responses) of the Regional, Season Specific and City/Season Specific models are compared and evaluated for general applicability of water demand models and results. The overall predictability of the three models is compared via a likelihood ratio test to determine if one model is superior to the others. An alternative water demand model functional form is examined as a test of robustness and sensitivity of the analysis.

CHAPTER 3

STUDY AREA CHARACTERISTICS AND DATA DEVELOPMENT

INTRODUCTION

A large portion of the time and effort expended by researchers on this study was devoted to collection and development of data, a necessary and critical component of empirical analysis. The information gathered and developed for this study was collected by many researchers at five universities. In addition, this study would not have been possible without the generous cooperation and invaluable assistance provided over a four-year period by participating utility staff. Collecting, assembling and refining the data necessary for this study was a formidable task, in part because of the traditional accounting and reporting practices of most water utilities. Historically, water utilities have not maintained their records in electronic form (until recently) or maintained records in a format suitable for analysis of long-term water demand conditions and the effects of conservation programs. In addition, record keeping within individual utilities has changed over time and varies among utilities. Initial data collection efforts were reviewed and revised based on researcher findings of data availability, quality and consistency. Many of the cities initially chosen for inclusion in this study were subsequently screened out due to changes in reporting practices and the lack of documentation of required information. Research methods also had to be substantially revised because of the lack of availability of detailed water consumption data and nonprice conservation program information.

Following the initial data collection and study area screening efforts, the number of study areas and period of time considered were increased to strengthen the overall research and extend the potential applicability of results. The collection, development, adjustments and documentation of the resulting database are described in more detail in a separate report entitled *Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database* (1997).

PROJECT STUDY AREAS

This study encompasses seven cities in three southwestern states: California, Colorado and New Mexico. The cities were selected because:

- They are representative of other cities in the semi-arid southwestern United States
- Several different rate structures and price levels have been implemented within individual cities and over time
- The water utilities in these cities have implemented a variety of types and number of conservation programs, from many programs to none
- The cities vary in size from small to large and in residential growth from slow to rapid
- They vary in climate and precipitation seasons
- They include areas that have experienced drought as well as areas that have not

The cooperation and interest of the utility districts in these cities were also instrumental in the inclusion and successful completion of this research. The study area cities and utility districts are:

California

City of Los Angeles - Los Angeles Department of Water and Power (LADWP)

City of San Diego - San Diego Water Utilities Department (SDWUD)

Colorado

City and County of Denver - Denver Water (DW)

City of Broomfield - Broomfield Water Department

New Mexico

City of Albuquerque - Albuquerque Water Utility Division

City of Santa Fe - Sangre de Cristo Water Company of Santa Fe

City of Las Cruces - Las Cruces Water Resources Department

CATEGORIES AND SOURCES OF INFORMATION

The data collected and developed for this study is grouped into four major categories: utility water use data; climatological data; socioeconomic data; and nonprice conservation program information. The types of information gathered and the sources used are described below. Summary statistics of the data for each study area are presented later in this chapter.

Utility Water Use, Accounts, Rate Structures and Revenues

The following information on aggregate single-family residential water use was collected from each of the seven water providers for each billing period as available over the period of study.

- Water use quantity per billing period
- Number of accounts (connections) per billing period
- Price and rate structure information
- Revenue collected per billing period

Utility records were maintained in a variety of formats: on computer printouts, in summary form, in annual reports, and sometimes electronically. Most data was collected and transcribed by hand from printed records. Also, because of differences in billing or reporting periods and changes in data definitions over the study period, time consuming and detailed efforts were required to verify and reconcile reporting differences and changes and to develop the data for purposes of consistency within and across study areas. For example, many of the utilities operate on bimonthly billing cycles, reporting two months of water use and revenue for approximately half of the total number of residential accounts each month. Information reported on this basis had to be disaggregated into partial monthly quantities and then reaggregated into total monthly quantities.

Climatological Data

Weather conditions are assumed to be an important factor in residential water use. Total monthly precipitation measured in inches and mean monthly temperatures measured in degrees Fahrenheit were collected for each study area. This information was obtained from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service periodical publications and reports for weather stations representative of each study area. The National Weather Service weather station index number used for each study area is identified below.

- Los Angeles - Los Angeles Civic Center, NWS station index no. 5115
- San Diego - San Diego WSO Airport, NWS station index no. 7740
- Denver - Denver WSFO Airport, NWS station index no. 2220
- Broomfield - Wheatridge 2, NWS station index no. 8995
- Albuquerque - Albuquerque WSFO Airport, NWS station index no. 0234
- Santa Fe - Santa Fe 2, NWS station index no. 8085
- Las Cruces - New Mexico State University, NWS station index no. 8535

Socioeconomic Data

Socioeconomic factors may also influence residential water use. The socioeconomic data listed below was collected from the: U.S. Department of Commerce, sources included the *1980 Census of Population, Characteristics of the Population, General Social and Economic Characteristics, 1990 Census of Population, Social and Economic Characteristics,* and the *1990 Census of*

Population and Housing Population and Housing Unit Counts. This was supplemented by local government information as available. Both median household income and population figures within the data set were linearly interpolated between 1980 and 1990 based on U.S. Census values. The growth rate between these two decades was linearly extrapolated from 1990 to the present. Also gathered were:

- Mean household size
- Median household income
- Number of households
- Population
- Population density per square mile

Nonprice Conservation Program Information

With the assistance of utility staff members, researchers endeavored to collect and compile the following information about nonprice conservation programs in a consistent fashion for each study area and for the region.

- Name and detailed description of each nonprice conservation program
- Date (month/year) of program implementation
- Program activity and duration (by month)
- Program intensity and coverage (number of people contacted, type and number of devices distributed or installed, number of education materials distributed, etc. by month and year)
- Other estimates of program effectiveness

Information about nonprice conservation programs was obtained by reviewing individual utility reports, memorandums and other internal and external documents and through personal communication with current and previous utility staff members. Typically, only information about current or planned nonprice conservation programs is presented in utility annual reports or long-term planning documents. Program duration was most frequently reported on an annual basis, although a given program may have been active for only one or a few months of the year such as a single mailing of literature. None of the utilities maintains a single comprehensive or continuing set of records that consistently identifies and describes the scope, coverage and intensity (effort) and lists the periods of implementation (in more detail than an annual basis) of their specific nonprice conservation programs. Because of the variability in reporting and lack of detail in records, the quality and consistency of information regarding the identification, description and duration of nonprice conservation programs is highly variable, both within and across study areas. The information compiled on individual nonprice conservation programs and the variables developed for the research analysis are documented in the report entitled *Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database* (1997). Summary information on the number and types of nonprice conservation programs that have been implemented in each study area is presented in Table 3.4.

RESIDENTIAL WATER USE, ACCOUNTS AND MONTHLY BILL

Total monthly and average numbers of accounts and single-family residential water use varies significantly among the study area cities. For example, over the two-year period from April 1993 through April 1995, in Los Angeles total single-family residential water use averaged 4.8 billion gallons per month or 12.4 thousand gallons per account per month. During the same period, total single-family residential water use in Santa Fe, New Mexico averaged 141 million gallons per month or just 7.1 thousand gallons per month per account. The widest variation in monthly residential water use per account was observed in New Mexico, where annual average use ranged from 7,050 gallons per month in Santa Fe to 15,440 gallons per month in Las Cruces. The total quantity of residential water used in a city is generally a reflection of the size of the city and number of accounts. Variations in the quantity of water used per residence or account within and between cities are assumed to be related to several other factors such as price, rate structure, climate, socioeconomic conditions and various nonprice conservation programs. These relationships are the focus of our water demand modeling and analysis.

Table 3.1 provides a summary of the total and monthly average, minimum and maximum residential water use, seasonal low and seasonal high water use, and total and monthly average revenue per account for each study area over the two-year period from April 1993 through April 1995. The presence of differences in water demand among cities, across seasons and over time is very important in identifying appropriate water demand models and in evaluating water demand relationships and consumer responses.

Across the region, average monthly summer use is 1.5 to 3.4 times greater than the average monthly winter/minimum water use. For example, during the winter, average monthly use per single-family residential account in Denver was 6,280 gallons; during the summer the average monthly use per account increased to 21,500 gallons. This seasonal demand pattern can be observed in each of the cities, as illustrated by the graph of Denver's monthly water use per single-family residential account shown in Figure 3.1.

Table 3.1 also shows the average monthly residential water use for Los Angeles and San Diego during the most recent severe drought. Although the impact of the drought on water supplies in California lasted for several years, the impact on consumers was buffered by storage capacity. The period of the drought that directly affected water users was defined by the California water providers as January 1991 to March 1993. During this time, a number of price and nonprice conservation programs, including temporary mandatory restrictions, were implemented by California utilities to encourage immediate reductions in water use. Figure 3.2 is a graph of monthly residential water use in Los Angeles. The apparent reduction in water use during the drought, and seeming return to previous water use levels, are examined in the statistical analysis of the water demand models.

The different quantities of water used and different utility rate structures and price levels in each city result in a wide range of the average monthly bills or costs per account. Annual average monthly bills per single-family account range from approximately $15.00 for residences in Denver, consuming the recent average of 11.9 thousand gallons per month, to almost $31.00 per residence in Los Angeles, consuming 12.4 thousand gallons per month. For many of the areas, the average maximum monthly bill is more than three times the average minimum monthly bill. The variations

Table 3.1
Water use statistics for single-family residential accounts by study area
April 1993 through April 1995

	Total Monthly Use (G)	Number of Accounts Per Month	Monthly Use Per SF Res. Acct (G)	Monthly Summer Use (G) per Acct.	Monthly Winter Use (G) per Acct.	Total Monthly Revenue $ (000)	Monthly Bill $ Per Account
LOS ANGELES							
Minimum	3,166,749	382,819	8.26	14.92	8.25	8,054.1	21.00
Maximum	6,526,893	394,331	16.71	16.7	11.03	17,298.4	44.28
Average	4,829,456	388,752	12.41	15.72	9.48	11,949.7	30.71
Avg. Drought			11.18	13.96	9.17		
SAN DIEGO							
Minimum	1,167,204	193,836	5.98	10.70	6.62	2,068.8	10.49
Maximum	2,875,050	197,307	14.79	14.79	8.82	5,443.9	28.00
Average	1,832,807	195,732	9.36	12.56	7.68	3,689.7	18.85
Avg. Drought			8.00	10.51	6.99		
DENVER							
Minimum	664,360	119,429	5.74	16.46	6.10	960.9	7.99
Maximum	3,147,242	121,085	27.37	27.37	6.51	3,912.9	32.45
Average	1,407,319	120,284	11.93	21.51	6.28	1,736.7	14.44
BROOMFIELD							
Minimum	44,161	7,338	5.23	12.77	5.23	130.1	16.07
Maximum	181,373	8,542	21.28	21.27	6.77	396.8	46.55
Average	91,367	8,033	11.42	17.97	6.18	220.7	27.55
ALBUQUERQUE							
Minimum	785,980	104,207	7.31	19.99	7.31	1,159.3	10.81
Maximum	3,064,545	107,928	27.58	28.60	8.70	2,939.5	26.63
Average	1,581,529	106,270	14.91	24.03	7.95	1,756.7	16.64
SANTA FE							
Minimum	82,162	19,463	4.11	7.56	4.77	392.8	19.67
Maximum	245,697	20,586	12.17	12.16	5.79	960.1	47.53
Average	141,003	20,037	7.05	10.01	5.26	596.7	29.82
LAS CRUCES							
Minimum	126,012	16,227	7.50	19.46	7.50	167.4	10.10
Maximum	495,477	17,260	29.07	29.07	9.25	552.8	32.44
Average	258,892	16,798	15.44	23.46	8.37	293.6	17.49

Source: *Residential Water Use, Rate, Revenue, and Nonprice Conservation Program Database* (1997).
Notes: Dollar values are in nominal term.s
Period of drought is defined as 1/91 though 3/93 (southern CA. water providers).
The information in this table represents the most recent two-year period shared by all study areas. G = 1,000 gallons.

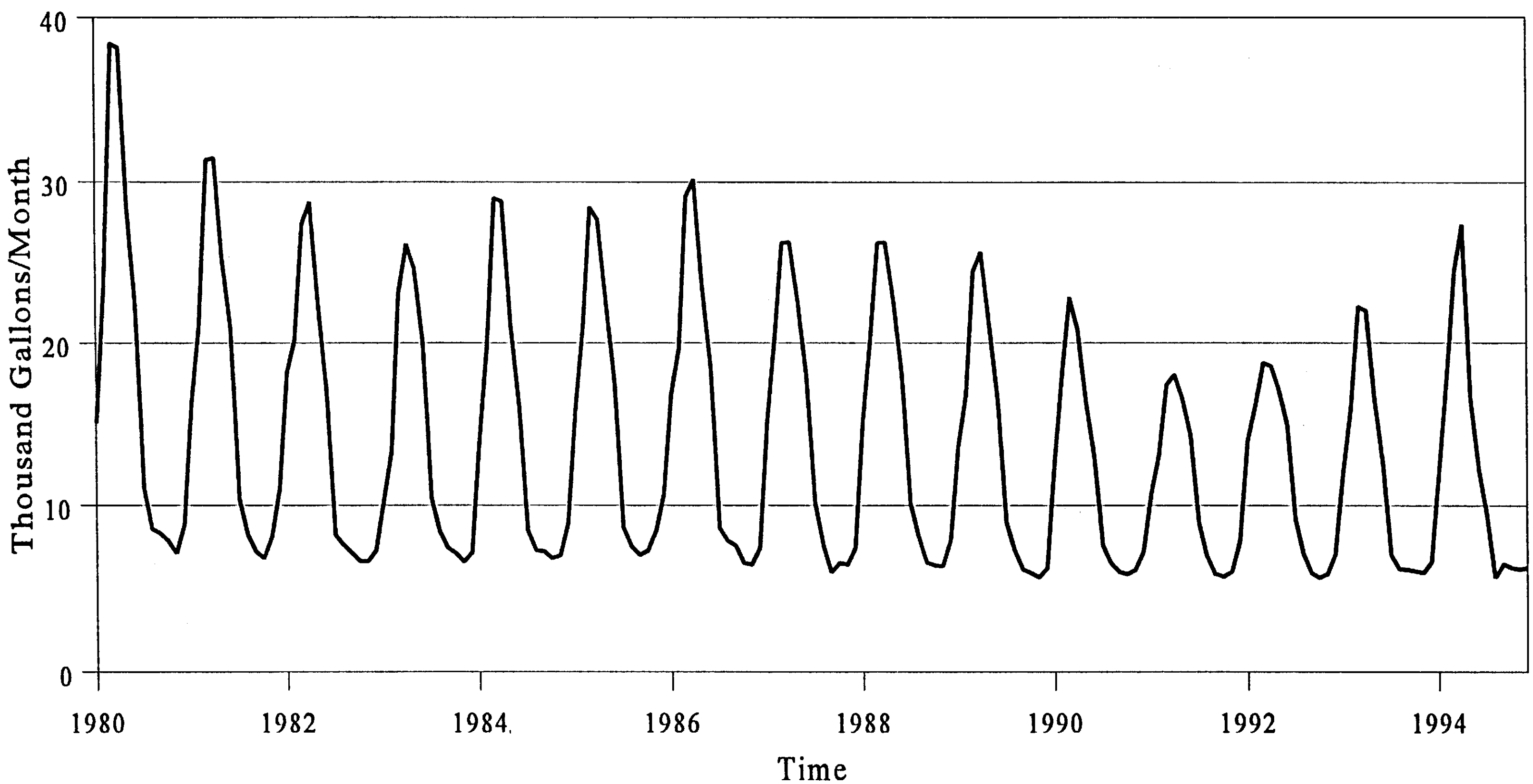


Figure 3.1 Denver monthly use per account

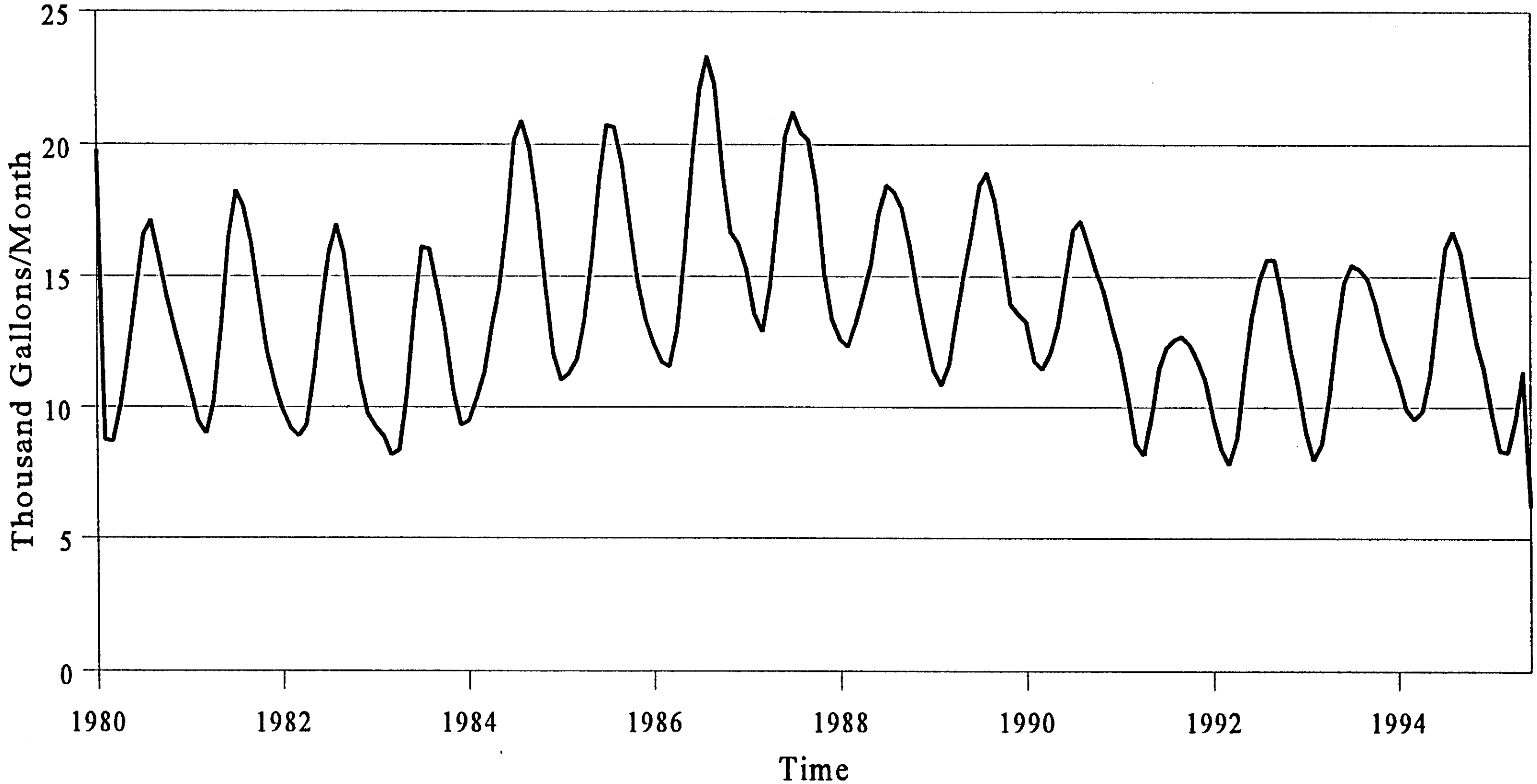


Figure 3.2 Los Angeles monthly use per account

in water use, price and other influencing factors within and across study areas and over time are modeled in the next chapter to help understand regional residential water demand in response to price and to evaluate the effectiveness of conservation programs.

DATA COVERAGE, BILLING CYCLES AND RATE STRUCTURES

The period of time covered by the models in this study is from January 1984 through April 1995. The water demand models require a concordance of observations for each city in the region. This means that the models described in chapter two must have an equal number of observations and the period of time that can be considered is restricted to the length of time that data is available in all of the study areas. Although researchers attempted to collect data starting from 1980, compatible data for San Diego could only be developed beginning in January of 1984. The period of data coverage, billing cycle, original reporting units of measurement, rate structure(s) and existence of nonprice conservation programs for each study area are summarized in Table 3.2. Four of the seven utility districts report (bill) residential water use on a monthly basis (Broomfield switched from bimonthly to monthly), two report use on a bimonthly basis, and one utility (SDWUD) reports use on two, four-week periods (13 periods per year). All of the data series used in this research were converted to a monthly basis.

Three of the seven utilities report and establish rates in terms of hundred cubic feet (HCF; equivalent to 748 gallons), while the other four use units of 1,000 gallons. Water quantities and prices reported in HCF were converted to a standard unit of measurement of 1,000 gallons.

Demand-side management or conservation programs include price and nonprice measures. Price measures include both price structure (uniform and increasing block rates) and price level. In addition to rate conservation programs, five of the seven utilities have implemented one or more nonprice conservation programs during the period of study. These are described later in this chapter.

Table 3.2

Study area billing cycles, measurement units, rate structures and nonprice programs

Study Area and Data Period	Billing Cycle	Units of Water	Rate Structure	Nonprice Conservation Programs
CALIFORNIA				
Los Angeles		HCF	01/80-11/92 SC + uniform	multiple ongoing programs
01/80-06/95	bimonthly		12/92-06/95 inclining & seasonal (2 bl)	
San Diego	13 periods per year & bimonthly	HCF	01/85-12/94 SC + inclining (2 bl)	multiple ongoing programs
01/84-04/95				
COLORADO				
Denver		1,000 gallons	05/80-12/89 SC + declining (4 bl)	multiple ongoing programs
04/80-04/95	bimonthly		01/90-02/90 SC + declining (2 bl)	
			03/90-06/95 SC + inclining (2 bl)	
Broomfield		HCF	10/80-04/95 SC + uniform	none
01/80-12/89	bimonthly			
01/90-04/95	monthly			
NEW MEXICO				
Albuquerque		HCF	1/80-8/82 SC + uniform & seasonal	publicity campaign (began 06/94)
1/80-10/95	monthly		9/82-8/88 SC + uniform & seasonal & seasonal reduction	
			9/88-6/93 SC + uniform & seasonal	
			7/93-10/95 SC + uniform & seas. + SCF	
Santa Fe		1,000 gallons	01/81-03/85 SC + declining & seasonal (2 bl)	few ongoing programs
01/81-09/95	monthly		04/85-09/93 SC + inclining (2 bl)	
			10/93-09/95 SC + inclining + SCF (2 bl)	
Las Cruces		1,000 gallons	11/82-06/87 SC + inclining (3 bl)	none
11/82-09/95	monthly		07/87-04/93 SC + inclining (4 bl)	
			05/93-09/95 SC + inclining + SCF (4 bl)	

Source: *Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database* (1997).

Note: SC denotes monthly/bimonthly service charge. bl denotes blocks withing a rate structure. SCF denotes a state conservation fee included in the utility rates.

Price and Rate Structure

The water utilities included in this study currently or have used uniform, declining, inclining or seasonal rate structures with fixed service charges independent of the quantity of water used.

Increasing block rates are considered to be conservation-oriented; that is, such rates provide consumers with incentives to conserve because higher use levels result in higher marginal rates per additional unit of water. However, the degree of incentive depends on how rapidly the marginal price increases and thus increases average price. Often utility rates structures are such that average price is decreasing because of a large fixed fee which is independent of marginal rates. This combination of fixed fees and increasing marginal rates send mixed signals to the consumer. There will be less incentive to reduce water use (conserve) if the minimum quantity supplied under the fixed charge is large and/or if the service charge and corresponding price per unit of water consumed is large in relation to the price per unit of the first or subsequent blocks of water consumed.

The water demand models developed for this study consider individual city as well as regional water demand and consumer price responsiveness. In addition, the models are specifically designed to test for consumer perception and response to alternative price structures. That is, are consumers responding to the average price of water consumed (price of the next unit of water consumed equals the total monthly bill divided by total number of gallons consumed) or, as is assumed by proponents of conservation and increasing block rate price structures, are consumers perceiving and responding to the marginal price of the next unit of water in an increasing block rate structure by reducing their use? The long-run, cross-sectional approach also distinguishes this study from most other studies by evaluating information about the regional and long-run (not just short-term) consumer perception and response to changes in water price. Knowledge of how consumers perceive and respond to price and alternative rate structures is critical to water managers in evaluating water demand and planning demand-management strategies and water supply requirements.

All but one of the seven utilities have changed their rate structure one or more times over the period of study, from uniform or declining rates to inclining and/or uniform plus seasonal rates, that is, more conservation-oriented rates. The type of rate structure(s) and time period(s) of implementation are summarized in Table 3.2.

Table 3.3 illustrates the complexity and changes in individual city service charges and uniform or declining/inclining block rates and quantities at three points in time: January 1980, January 1990 and January 1995. Because of the large number of rates over this period of time, a complete listing of all rate structures and price levels is beyond the scope of this report. For example, over the 15-year period from January 1980 through April 1995, there were 43 different single-family residential account price levels in effect in Los Angeles. Detailed information on individual utility rate

Table 3.3

Rate structures and prices by study area: 1980, 1990 and 1995

(quantities in thousand gallons; prices not inflation adjusted; first two block rates only)

City	Date	Rate Type	Service Charge	Block 1		Block 2	
				Price	Quantity	Price	Quantity
Los Angeles	1/80	SC + Uniform	$3.10/mn	$0.69			
	1/90	SC + Uniform	$2.40/mn	$1.47			
	1/95	Inclining & Seasonal	- none -	$2.50	0-16 Nov-May 0-20 Jun-Oct	$3.11	>16 Nov-May >20 Jun-Oct
San Diego	1/84	SC + Inclining	$2.44/bill	$0.89	0-7.5	$1.03	>7.5
	1/90	SC + Inclining	$3.12/bill	$1.25	0-7.5	$1.44	>7.5
	1/95	SC + Inclining	$3.12/bill	$1.73	0-7.5	$1.91	>7.5
Denver	1/80	Declining (4 bl)	- none -	$0.70	0-10	$0.43	11-40
	1/90	SC + Declining (2 bl)	$3.00/mn	$0.83	0-15	$0.67	16-35
	1/95	SC + Inclining (2 bl)	$3.66/mn	$1.08	0-11	$1.29	>11
Broomfield	1/80	SC + Uniform	$1.50/mn	$0.85			
	1/90	SC + Uniform	$5.08/mn	$1.63			
	1/95	SC + Uniform	$5.86/mn	$1.88			
Albuquerque	1/80	SC + Uniform/Seas.	$2.50/mn	$0.41	use > 250% winter avg. $0.27/G		
	1/90	SC + Uniform/Seas.	$5.19/mn	$0.69	use > 400% winter avg. $0.28/G		
	1/95	SC + Uniform/Seas.	$4.84/mn	$0.91	use > 200% winter avg. $0.28/G		
Santa Fe	1/80	SC + Declining/Seas	$3.00/mn	$1.72 $2.79	0-5 winter 0-5 summer	$1.37 $2.43	>5 winter >5 summer
	1/90	SC + Inclining	$6.94/mn	$2.97	0-5	$3.47	>5
	1/95	SC + Inclining	$6.94/mn	$3.00	0-5	$3.50	>5
Las Cruces	1/83	SC + Inclining (3 bl)	$4.00/mn	$0.46	0-25	$0.58	26-50
	1/90	SC + Inclining (4 bl)	$4.61/mn	$0.44	0-5	$0.49	6-10
	1/95	SC + Inclining (4 bl)	$5.14/mn	$0.58	0-5	$0.63	6-10

Source: Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database (1997).
Note: SC denotes service charge per month (mn) or billing period (bill). bl denotes blocks within a rate structure.

structures and price levels in each study area are documented in a separate report entitled *Residential Water Use, Rate, Revenue and Nonprice Conservation Program Information* (1997). Monetary values used in the water demand models and analysis were adjusted for inflation to constant 1995 dollars using the U.S. Department of Labor, Bureau of Labor Statistics, Consumer Price Index.

NONPRICE CONSERVATION PROGRAMS

A large number of nonprice conservation programs have been implemented by water utilities in the seven study area cities with the expectation that they will encourage either short-term and/or long-term reductions in residential water use. Examples of nonprice residential conservation programs that have been implemented include: television and radio announcements on the importance of conserving water, newspaper articles and advertisements, bill inserts, public distribution of conservation literature, school visits, speakers bureaus, school poster contests, educational videotapes, widespread distribution of retrofit devices, selected installation of retrofit devices, residential audits, water efficient appliance rebates, xeriscape demonstration gardens, metering programs, lawn watering guidelines and regulations, revised plumbing codes, and emergency ordinances and regulations.

In order to evaluate, verify and quantify the effectiveness of individual nonprice conservation programs, it is necessary to have accurate information about specific program activities, levels of effort, scope and coverage and the exact periods of program duration corresponding with activities and levels of effort. This information was often difficult or impossible to obtain from existing utility records. For example, we found that similar programs were often aggregated and were reported without descriptions of individual programs or dates of implementation and measures of specific program efforts. Reports might simply state that several different education programs were implemented over a period of years (and without further documentation it was assumed they were effective). Aggregation was particularly common in the reports of education and public information programs. Among the nonprice conservation programs, retrofit programs requiring significant utility expenditures for the distribution or installation of physical (easily countable) devices typically had the best documentation. The unavailability of information and variation in the level of detail, accuracy and consistency of information about nonprice conservation programs maintained by water and other utilities is a major hindrance in evaluating the effectiveness of these programs.

Programs targeted to influence a particular type of residential water demand are often conducted for periods of one month or less or for only a few months. However, the duration of activity of nonprice conservation programs were usually reported on an annual, rather than a monthly, basis.

Reporting these programs on an annual basis significantly diminishes the ability to correlate changes in water demand with a specific nonprice conservation program.

The nonprice conservation program information that is available is often reported in different terms or measures over time within a utility (because of changes in reporting methods, focus or personnel) and almost always with different descriptions and measures than are used by other utilities. Because of the differences in definitions and measures and missing or unavailable information, it was not possible to develop consistent variables for this analysis that would accurately reflect the scope and level of effort of each of the individual nonprice conservation programs or types of programs that would be comparable over time and/or between utilities.

Although it is recognized that utility resources are limited and nonprice conservation program documentation can be a difficult and time consuming task, we strongly recommend that resources be dedicated to developing and maintaining detailed, consistent documentation regarding nonprice conservation programs and efforts. This will enable water utility managers in the future to better monitor, evaluate and document the effectiveness of their programs and to implement the programs that will suit their needs.

Types and Categories of Nonprice Conservation Programs

To help in understanding the type and scope of nonprice conservation efforts, individual residential programs implemented by each utility were grouped into five major categories. The five categories and examples of the types of programs in each classification are listed below.

1. **Public Information Programs:** Public information programs focus on conveying the methods and importance of water conservation for consumers throughout a utility's service area. Programs in this category include:

- *home water surveys* that offer a home water use analysis; services generally include on-site inspection and calculation of showerhead and sink faucet flow rates, leak inspection, installation of showerheads and toilet displacement devices and efficient landscape and irrigation recommendations

- *conservation hotline* to address customers questions and concerns regarding water conservation issues
- *printed material*: for example, bill inserts and literature available at utility offices providing conservation tips
- *speakers bureaus:* individuals available to give water conservation presentations to interested groups or schools
- *xeriscape programs* to increase customer knowledge and practice of low-water, low-maintenance landscape techniques
- *demonstration gardens* to display efficient landscape alternatives
- *new homeowner outreach programs* to provide information on low-water intensive landscape alternatives
- *evapotranspiration programs* to publicize daily evapotranspiration estimates, the amount of lawn irrigation water needed based on local daily climate and seasonal growing conditions
- *neighborhood watch programs* to encourage the elimination of wasteful practices and providing tips on improving water efficiency in the home
- *water rotation schedules* to distribute lawn watering guides based on odd/even house numbers or several day rotations
- *bus stop boards*, a *painted bus* and *billboard*s throughout the city as well as *televisio*n *program*s and *commercial*s, *radio (psa) announcements* and *newspaper articles* to convey methods and the importance of water conservation

2. **Education (school) Programs:** Education programs focus on incorporating water conservation information into school curriculum. Programs may consist of a single presentation or class projects lasting throughout the semester. Programs include:

- *presentation*s to classrooms stressing the importance of incorporating water saving practices into our every day lives
- *poster contests* to enlist participation from children in local schools. Winning drawings are included in water rotation calenders distributed to customers

3. **Retrofit Programs:** Retrofit programs promote the installation of devices that contribute to the reduction of water use within the home. Programs include:

- *rebate programs* to encourage the installation of water conservation devices, such as low-flow showerheads, by reducing the cost
- *retrofit installation programs* where the utility provides and/or installs water saving devices such as ultra low-flow toilets
- *school retrofit programs* to provide students with low-flow devices to take and install in their own homes
- *distribution of retrofit kits* to encourage customers to install retrofit devices, such as toilet dams and faucet restrictors, in their homes

4. **Permanent Ordinances and Regulations:** Permanent or ongoing ordinances or regulations intended to affect water consumption. For example, ordinances that require the installation of ultra low-flow toilets, showerheads and faucets in all newly constructed or remodeled bathrooms. Such requirements also stem from Federal energy conservation legislation.

5. **Temporary Ordinances and Regulations:** Ordinances or regulations that temporarily restrict certain types or times of water use and/or restrict the level of residential use by a specified amount. Some restriction programs may be activated only during times of severe water shortages and cease after the threat of such shortages have passed.

Nonprice Conservation Programs by City and Year

Table 3.4 indicates the number of "major" conservation programs implemented for the single-family residential sector on an annual basis in each city. Tables 3.5 through 3.9 indicate the number of programs within each nonprice conservation category for each study area city. The last row of each table shows the total number of nonprice conservation programs individual study areas had in place each year. Specific programs employed by each utility are described in more detail in a separate report entitled *Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database* (1997). Tables are shown for five of the seven study areas -- Los Angeles, San Diego, Denver, Albuquerque and Santa Fe -- that had implemented nonprice conservation programs between 1980 and 1995. Broomfield and Las Cruces did not implement nonprice conservation programs during the period of study. Given the limited availability of nonprice program information, the classification and tallying of individual programs may be characterized as more of an art than scientific determination.

Table 3.4
Annual number of active residential nonprice conservation programs by city

City	Number of Nonprice Conservation Programs By Year															
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Los Angeles	3	3	6	6	6	7	7	7	9	9	12	14	12	11	11	11
San Diego	5	6	6	6	6	6	6	7	7	7	8	11	12	15	15	15
Denver	4	5	5	5	5	6	6	6	6	8	11	12	13	12	10	10
Broomfield	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Albuquerque	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6
Santa Fe	0	0	0	0	0	0	0	0	1	1	4	3	3	3	3	3
Las Cruces	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database (1997).

Table 3.5
Residential nonprice conservation programs implemented in Los Angeles

Conservation Category	Number of Programs In Each Conservation Category By Year															
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Public Information	1	1	5	5	5	6	6	6	6	6	7	7	7	7	7	7
Education	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Retrofits	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Ordinances	0	0	0	0	0	0	0	0	2	2	3	4	2	2	2	2
Restrictions	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Programs in effect	3	3	6	6	6	7	7	7	9	9	12	14	12	11	11	11

Source: Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database (1997).

Table 3.6

Residential nonprice conservation programs implemented in San Diego

Conservation Category	Number of Programs In Each Conservation Category By Year															
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Public Information	5	6	6	6	6	6	6	7	7	7	8	9	10	11	11	11
Education	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Retrofits	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2
Ordinances	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Restrictions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Programs in effect	5	6	6	6	6	6	6	7	7	7	8	11	12	15	15	15

Source: Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database (1997).

Table 3.7

Residential nonprice conservation programs implemented in Denver

Conservation Category	Number of Programs In Each Conservation Category By Year															
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Public Information	3	4	4	4	4	5	5	5	5	7	9	10	10	9	9	9
Education	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Retrofits	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0
Ordinances	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Restrictions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Programs in effect	4	5	5	5	5	6	6	6	6	8	11	12	13	12	10	10

Source: Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database (1997).

Denver Water implemented the Universal Metering Program in 1987. The focus of the program was to convert all single-family residential unmetered accounts to a meter basis. Although the program was initiated as a nonprice conservation effort by the utility, the effect of metering is felt by consumers as responsiveness to marginal price, and thus, is captured by the marginal price coefficient.

Table 3.8
Residential nonprice conservation programs implemented in Albuquerque

Conservation Category	Number of Programs In Each Conservation Category By Year															
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Public Information	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	6
Education	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Retrofits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ordinances	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Restrictions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Programs in effect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6

Source: Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database (1997).

Table 3.9
Residential nonprice conservation programs implemented in Santa Fe

Conservation Category	Number of Programs In Each Conservation Category By Year															
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Public Information	0	0	0	0	0	0	0	0	1	1	4	3	3	3	3	3
Education	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Retrofits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ordinances	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Restrictions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Programs in effect	0	0	0	0	0	0	0	0	1	1	4	3	3	3	3	3

Source: Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database (1997).

GEOGRAPHIC, CLIMATE AND SOCIOECONOMIC CHARACTERISTICS

The seven urban water districts included in this study encompass a wide range of geographic, socioeconomic and climatic conditions. A wide variation in conditions is important for identifying significant and reliable water demand relationships. Table 3.10 provides a summary of the geographic, climate and socioeconomic conditions in each of the study areas.

Table 3.10
Summary of geographic, socioeconomic, and climate characteristics

	California		Colorado		New Mexico		
Char./Study Area	**Los Angeles**	**San Diego**	**Denver**	**Broomfield**	**Albuq.**	**Santa Fe**	**Las Cruces**
Geog./Socioecon.							
Land Area (sq. miles)	469.3	324	154	23.97	132.2	36.6	37.5
Elevation (feet)	267	13	5,280	5,362	5,311	7,200	3,881
Population (1,000)*	3,485	1,110	467	24	384	55	62
Density (pop./mile)*	7,389	3,933	4,212	1,104	2,910	1,526	1,656
People/household*	2.80	2.61	2.17	2.83	2.46	2.39	2.59
HH Income (median)*	30,925	33,686	25,106	39,067	27,555	30,023	23,648
Climatological							
Precipitation (inches)	15	9.5	15.2	15.2	8.5	14.0	8.0
Temperature (summer)	85-65^0	75-65^0	88-58^0	88-59^0	93-65^0	84-57^0	94-65^0
Temperature (winter)	72-62^0	65-45^0	42-15^0	44-19^0	47-22^0	41-19^0	56-25^0
Precipitation season	Winter	Winter	Annual	Annual	Summer	Summer	Summer
Water Use							
High use months	Jul, Aug, Sept	Jul, Aug, Sept	Jul, Aug, Sept	Jul, Aug, Sept	Jun, Jul, Aug	Jun, Jul	Jun, Jul
Low use months	Jan, Feb, Mar	Jan, Feb, Mar	Jan, Feb	Jan, Feb	Jan, Feb	Jan, Feb	Jan, Feb
Avg. monthly water use per acct. (1,000 gal.)**	12.68	9.66	12.60	12.03	14.76	7.06	15.66

Source: Residential Water Use, Rate, Revenue and Nonprice Conservation Program Database (1997).
Notes: * 1990 Data. ** 1994 Data.

Although all of the study areas are in the southwestern United States, the distance between some of them is greater than 1,000 miles. There are large differences in the physical geography of the areas ranging from low elevation coastal regions (San Diego is 13 feet above sea level and Los Angeles is 267 feet above sea level) to high plains areas in and near the Rocky Mountains (Santa Fe is 7,200 feet above sea level, and Denver is 5,280 feet above sea level).

The differences in physical geography are reflected in the climate and seasonal variations. All of the study areas can be characterized as semi-arid or arid with total annual precipitation averaging between eight and fifteen inches. The quantity and timing of precipitation is very important in terms of outdoor residential water demand. The seasons of precipitation vary from summer (New Mexico) to winter (California) to year-round (Colorado). Temperatures are also assumed to be a factor in residential water demand. The average summer high temperatures range from 75°F (San Diego) to 94°F (Las Cruces). Average winter high temperatures range from 41°F (Santa Fe) to 72°F (Los Angeles).

The populations served by water districts in the study range from 24,000 people in Broomfield (1990) to almost 3.5 million people in Los Angeles (1990) and the area of land ranges from just 24 square miles (Broomfield) to over 469 square miles (Los Angeles). These conditions are reflected in the density of population statistics, from a low of approximately 1,000 people per square mile in Broomfield to a high of 7,389 people per square mile in Los Angeles. The number of people per household may also influence water demand. The average number of people per household ranges from 2.17 in Denver to 2.83 in Broomfield (1990). Some studies have suggested an association between income (number and efficiency of appliances) and water demand. Median income per household was $23,648 in Las Cruces and $39,067 in Broomfield (1990). For perspective, Table 3.10 shows use per single-family household in 1994.

REGIONAL WATER DEMAND MODEL

The Regional demand model relates residential water use to price, income, climate and conservation variables, but does not distinguish between cities or between seasons. Note, also that the use of marginal and average price may not capture all price impacts of alternative price structures. The model, developed in Chapter 2, is reproduced here.

$$\ln(Q_t) = b_0 + b_1 \ln(MP_t) + b_2 \ln(AP/MP_t) + b_3 \ln(INC_t) + b_4 \ln(TEMP_t) + b_5 \ln(PREC_t) + b_6 \ln(ACCT_t) + b_7 (CONS_t) + b_8 (Drought_t) + b_9 (Time_t) + M \quad (2.7)$$

where the following is the list of variable names and definitions:

1. Q_t = total city monthly residential water quantity consumed at time t;
2. MP_t = marginal price per 1,000 gallons, the price appropriate for the average consumption in the city for that month;
3. AP/MP_t = ratio of average price to marginal price, the monthly total single-family residential revenue divided by total single-family residential monthly water use for that city;
4. INC_t = average monthly household income for that city;
5. $TEMP_t$ = average monthly temperature;
6. $PREC_t$ = total monthly precipitation;
7. $ACCT_t$ = number of single-family residential accounts for that month and city;
8. *CONS* = number of conservation programs in effect;
9. *Drought* = binary variable for drought conditions in southern California during January 1991 through March 1993;
10. *Time* = time, year and month on a fractional year basis;
11. *M* = normally distributed error.
12. b1 .. b9 are coefficients to be estimated, referred to as "betas."

Table 4.1 presents the estimated coefficients, standard errors, significance level (probability that the coefficient estimate is not significantly different than zero), mean log (transformed) value and mean linear (untransformed) value for each of the regression variables in the Regional model. The demand model estimates and variable values are for the period from January 1984 through April 1995. All prices and values are in inflation adjusted 1995 dollars (1995$).

The coefficient estimates, with the exception of income, precipitation and time, have the expected relationship to water demand (sign). The estimates for Precipitation and Drought effects on demand are not significantly different from zero at a 95 percent level of confidence. The insignificant drought coefficient (*Drought* = -0.027) suggests that this experience did not influence residential water use in southern California cities above the aggressive price and nonprice conservation programs that were in effect at the time of the drought. The passage of time (*Time* = 0.026) has a significant, positive relationship to water use, indicating that regional water use apart from price and nonprice conservation programs is increasing by 2.6 percent annually (this indicates a possible misspecification of the model in that there are unknown demand effects related to time). The coefficient for accounts (*Acct* = 1.151) is statistically greater than one suggesting that household use increases as cities get larger (this was not expected and may be an indirect income effect). Temperature (*Temp* = 0.805) has a significant and positive impact on water use while precipitation (*Prec* = 0.00022) is statistically insignificant. Price and conservation effects are discussed in the following sections.

Table 4.1

Regional water demand model estimated coefficient results

Variable	Coefficient	Standard Error	Significance Level	Mean Log Value†	Mean Linear Value†
Constant	-36.342	9.286	0.000	n/a	n/a
Acct	1.151	0.016	0.000	10.82	114,569
AP/MP	-0.397	0.049	0.000	0.23	1.27
MP	-0.121	0.033	0.001	0.37	1.72
Drought	-0.028	0.038	0.464	n/a	n/a
Time	0.026	0.005	0.000	n/a	n/a
Income	-1.71	0.195	0.000	10.38	32,352
Temp	0.805	0.040	0.000	3.99	56.13
Prec	0.227E-03	0.23E-02	0.921	-0.49	1.16
Cons	-0.029	0.003	0.000	n/a	3.48

† Values for the period January 1984 through April 1995.

Price Responsiveness Under the Regional Model

Based on the results of the Regional model, residential water demand across all study area cities is very price inelastic, that is, consumers are very unresponsive to changes in price. The estimated regional price elasticity of -0.04 indicates that for a one percent increase in price, water use on average would only decrease by four hundredths of one percent. This indicates that demand is much more price inelastic than previously estimated by most other water demand studies. This has important implications for utility managers involved in forecasting demand, evaluating price and rate designs and in overall resource planning. Very large price increases are needed to substantially reduce water demand under current (service charge and tiered block) rate structures.

Price elasticities of demand are calculated by measuring the estimated change in residential water use as the marginal price increases. There are two price effects: (1) the direct marginal price effect; and (2) the effect of average price which also increases as marginal price rises. Because of the multiplicative demand specification there is an interaction of average and marginal price effects that may amplify or counteract each other. The empirical calculation of price elasticity proceeds in steps: (1) current water use is the base of reference; (2) total water bill is calculated on current use and the appropriate rate structure including the service charge; (3) the current total water bill is divided by current use to derive the base average price; (4) using the marginal price for the appropriate block of current use a new total bill is calculated with a 10 percent increase in marginal price; (5) new average and marginal prices are calculated (the average price assumes that use is constant - this approximation involves a small degree of error but avoids simultaneity problems); (6) new marginal and average prices are entered into the regression equation to derive the new estimated water use; and (7) the change in water use is calculated on a percentage basis and divided by the 10 percent price increase to yield the elasticity estimate. Note that the elasticity is not constant at different use levels. Given that equation 2.7 is a constant elasticity demand function, this result seems inconsistent. But the combination of average and marginal price variables in the model can result in variable elasticity over seasonal ranges.

Table 4.2 illustrates the impact on water use and a residential monthly water bill on a seasonal basis for a 10 percent increase in the marginal water price. To derive elasticity estimates, a representative regional rate structure and seasonal use pattern from the database was used to predict the consequences of a 10 percent marginal price increase. The elasticity estimate is more complicated than simply the coefficient in the demand equation. There is an interaction between AP and MP elasticities. Furthermore, the service charge component of average price insures elasticity does not stay constant over the seasonal use range. (The elasticities are calculated using a series of intermediate steps in a spreadsheet). The rate structure contained the following components: A monthly service charge of $5.00; the first block is priced at $1.50 per 1,000 gallons for use below 16,000 gallons; and the second block price is priced at $2.00 per 1,000 gallons for use greater than 16,000 gallons. The monthly bill associated with this rate structure and use patterns by season is indicated in row 1. The last two rows of Table 4.2 indicate the estimated change in water use per account predicted by the Regional model and the associated water price elasticity and the associated water price elasticity holding all other variables constant. Notice the price elasticity varies from season to season only because of different use levels (the estimated price coefficients are the same for all seasons). Consumers are more responsive to price in the summer (-0.06) than during the winter (-0.01). However, the overall seasonal elasticity estimate of -0.04 is highly inelastic indicating that residential water users respond only slightly to changes in the rate structure.

Consumer Price Perception

Using the Shin price perception test outlined in Chapter 2, we evaluated whether consumers respond to marginal prices or average prices. From the Regional model estimated coefficients for marginal price and the ratio of average to marginal price, the value of the Shin test statistic ($k = 3.28$) is statistically different from 1.0, the value of k if consumers are responding to average price. The Regional model results suggest that consumers do not respond solely to marginal price or average price, rather they respond to some combination of the two.

Table 4.2

Regional water demand model: Estimated response to a 10% increase in price

	Spring	Summer	Fall	Winter	Seasonal Avg.
Monthly bill 1995$	21.50	33.00	23.00	17.00	23.63
10% increase in marginal price $	23.15	35.80	24.80	18.20	25.49
Use/acct. (1,000 gallons/month)	11.00	18.00	12.00	8.00	12.25
Use/acct. after price change	10.97	17.90	11.96	8.00	12.21
Elasticity	-0.03	-0.06	-0.03	-0.01	-0.04

Nonprice Conservation Effects Under the Regional Model

Nonprice conservation programs (*Cons* = -0.029) have significant, negative influence on water use. The nonprice conservation parameter is a measure of the number of programs that are in effect at that particular point in time. Because the information regarding nonprice programs is incomplete, the model and this parameter are not able to distinguish individual types or specific programs nor the residual or lasting effects of nonprice programs. Based on the results of the Regional water demand model, residential water use can be reduced on average by 2.9 percent per nonprice conservation program. This regional estimate is driven by the aggressive programming efforts of several cities. However, results from the City/Season Specific water demand model will indicate that conservation responsiveness in individual cities is lower, and in some cases even zero. Furthermore, the 2.9 percent per program probably overstates the total conservation effect for cities such as Los Angeles and San Diego cities that had numerous programs already in effect from the beginning of the period analyzed.

Predictive Capability of the Regional Model

Because the Regional model was estimated using maximum likelihood regression techniques, there is no "goodness of fit" measure such as R^2, (the likelihood value is difficult to interpret). However, it is possible to compare predicted estimates to actual use values for the database using the following simple linear regression model:

$$Actual_t = b_0 + b_1\ (predicted_t) \tag{4.1}$$

where $actual_t$ is the observed water use per month for all seven cities, and $predicted_t$ is the predicted water use of the Regional model applied to the database (often called sample prediction or forecast).

The Regional model attempts to explain the diverse water use relationships and patterns in all seven cities. The R_2 regression results of predicted versus actual water demand is a relatively high 96 percent, but the results also suggest that the Regional model estimates have some bias in that predicted water use under estimates actual use by approximately nine percent (b_1 = 1.09). The Regional Model is the most general and has the broadest range of variation in the variable

Table 4.3

Regression results (predicted vs actual) of regional model

Regression Results	
R Squared	0.967
No. of Observations	943
Degrees of Freedom	941
Beta Coefficient (b_1)	1.0901
Std error of (b_1)	0.0200
Constant (b_0)	-47229

observations that it attempts to explain (Table 4.3). In applying estimates of the Regional and other models to make predictions the best (most reliable) results will be obtained by using variable values near the average and within the range of variable observations. Table 4.4 outlines the range in average and marginal prices and number of conservation programs that are implicit in the Regional model estimates. The data range illustrates the appropriate limits of variable values for scenario predictions. Again, the best predictions would be near the regional average value for each variable.

Figure 4.1 illustrates the predictive capabilities of the Regional model comparing predicted use against actual residential use in each city. Each vertical grid of the graph represents the start of the time series for a specific city (labeled along the bottom of the graph). The graph illustrates a twelve month moving average or long-term trend in water demand for each of the seven cities. It is apparent from this graph that the Regional model under predicts water use in Los Angeles and Denver. However, the Regional model captures most trend effects and accounts for differences in average use between cities.

Table 4.4

Data range for the regional model

Variable	Maximum	Minimum	Average
Average Price 1995$	$5.82	$1.00	$2.05
Marginal Price 1995$	$5.03	$0.54	$1.72
Conservation programs (#)	16	0	4.21

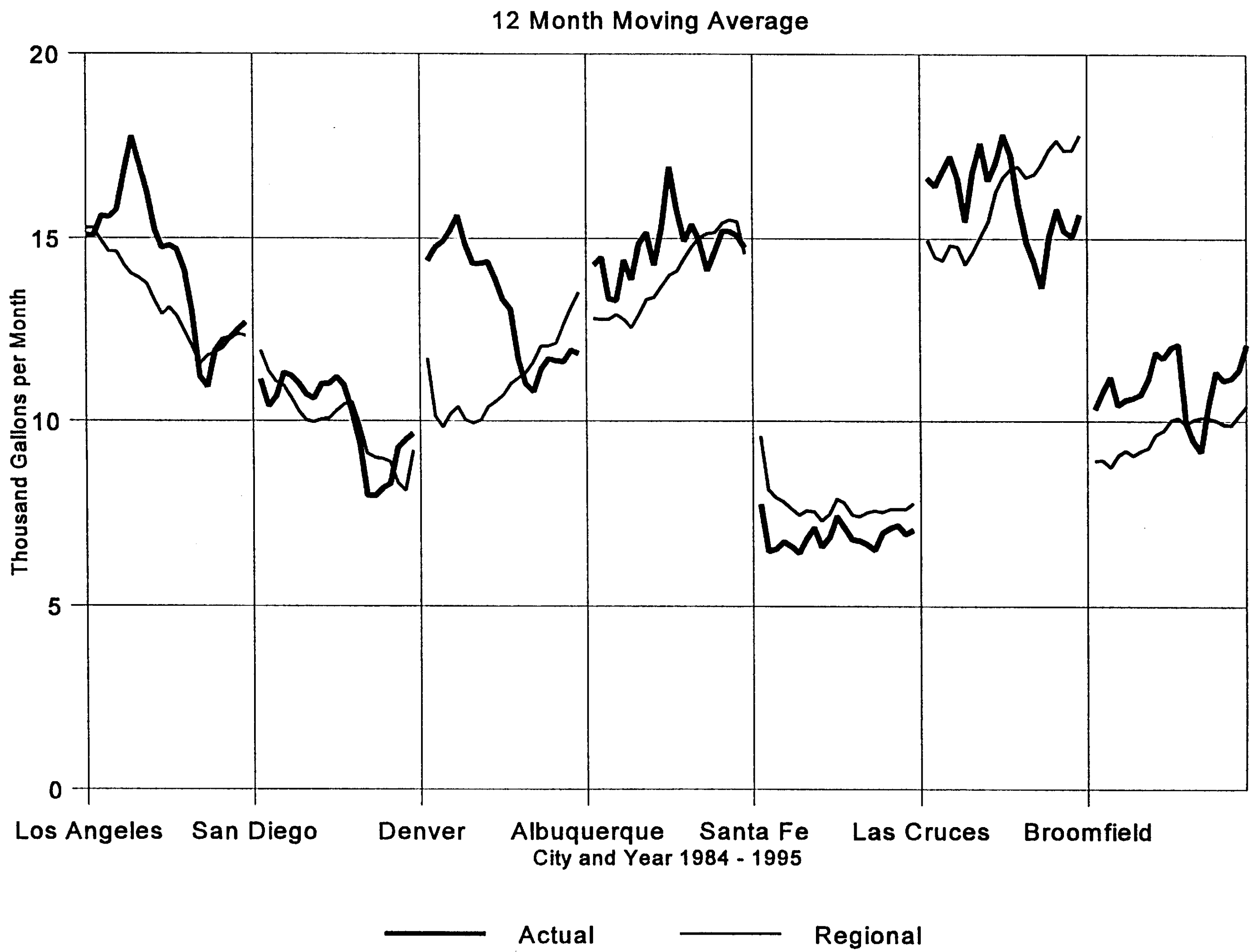


Figure 4.1 Regional model predicted and actual water use

The Regional model has the most general estimates of water demand relationships, and in the absence of specific city or seasonal information the model results may prove useful in estimating water demand and influences in other cities in the region. Because the estimates of the Regional model are based upon observations of seven cities in the southwestern United States, the most appropriate use of the model is comparing the effects of price and nonprice conservation programs and other water demand influences across the study area cities and with other cities in the semi-arid western and southwestern United States.

SEASON SPECIFIC MODEL

The Season Specific model disaggregates price, temperature and conservation variables according to season, spring, summer, fall and winter. Water demand relationships (variable coefficients) are estimated for each season. The Season Specific model is a regional model and the coefficients are estimated based on the observations of all seven cities. The Season Specific model is formulated as follows:

$$\ln (Q_t) = b_0 + \Sigma_{I=1..4} [b_{1i} \ln (MP_{it}) + b_{2i} \ln (AP/MP_{it})] + b_3 \ln (INC_t) + \Sigma_{I=1..4} b_{4i} \ln (TEMP_{it}) + b_5 \ln(PREC_{it}) + b_6 \ln(ACCT_t) + \Sigma_{I=1..4} b_{7i} (CONS_{it}) + b_8 (Drought_t) + b_9 (Time) + M \quad (2.7)$$

where the following is the list of variable names and definitions:

1. Q_t = total city monthly residential water quantity consumed at time t;
2. MP_t = marginal price per 1,000 gallons defined on a seasonal basis, (the variable has the observed value for the applicable season; zero otherwise);
3. AP/MP_t = ratio of average price to marginal price defined on a seasonal basis, (the variable has the observed value for the applicable season, zero otherwise);
4. INC_t = average monthly household income for that city;
5. $TEMP_t$ = average monthly temperature defined on a seasonal basis, (the variable has the observed value for the applicable season, zero otherwise);
6. $PREC_t$ = total monthly precipitation;
7. $ACCT_t$ = number of single-family residential accounts for that month and city;

8. *CONS* = number of conservation programs defined on a seasonal basis, (the variable has the observed value for the applicable season, zero otherwise);
9. *Drought* = binary variable for drought conditions in southern California during January 1991 through March 1993;
10. *Time* = time, year and month on a fractional year basis;
11. *M* = normally distributed error.
12. b1 .. b9 are coefficients to be estimated, referred to as "betas."
13. The index (i) refers to season.

Season Specific Water Demand Model Results

Table 4.5 presents the estimated coefficients, standard errors, significance level (probability that the coefficient estimate is not significantly different than zero), mean log (transformed) value and mean linear (untransformed) value for the variables in the Season Specific model. The demand model estimates and variable values are for the region for the period from January 1984 through April 1995.

The coefficient estimates, with the exception of income and the average/marginal price ratio in fall have the expected sign (water demand relationship). The estimates for the average/marginal price ratio in fall, drought and precipitation are not significantly different from zero at a 95 percent level of confidence. The insignificant drought coefficient (*Drought* = -0.068) is the same as the Regional model. The passage of time *(Time* = 0.014) has a significant, positive relationship with water use, increasing by 1.4 percent annually. The coefficient for number of accounts (*Acct* = 1.111) is significant and statistically greater than one suggesting that household use increases as cities get larger. Temperature is significant and has approximately the same effect in all seasons as the Regional model. Precipitation again *(Prec* = -0.002) is insignificant.

Price Responsiveness With the Season Specific Model

The seasonal average price elasticity (−0.15) of the Season Specific model is slightly more elastic or responsive to price than the estimate under the Regional model (note that elasticities are not directly obtained from price coefficients because of the interaction of AP and MP and must be

Table 4.5

Season specific water demand model results

Variable	Coefficient	Standard Error	Probability that the coefficient is not significant	Mean Log Value †	Mean Linear Value †
Constant	-15.217	7.506	0.043	n/a	n/a
Acct	1.111	0.013	0.000	10.82	114,549
AP/MP Spring	-0.337	0.066	0.000	0.22	1.26
AP/MP Summer	-0.237	0.088	0.007	0.13	1.15
AP/MP Fall	0.022	0.080	0.787	0.17	1.19
AP/MP Winter	-0.401	0.069	0.000	0.33	1.43
MP Spring	-0.210	0.324	0.000	0.40	1.71
MP Summer	-0.282	0.311	0.000	0.41	1.75
MP Fall	-0.190	0.033	0.000	0.41	1.75
MP Winter	-0.091	0.034	0.009	0.34	1.66
Drought	-0.062	0.035	0.076	n/a	n/a
Time	0.014	0.003	0.000	n/a	n/a
Income	-1.396	0.142	0.000	10.39	32,875
Temp Spring	0.780	0.039	0.000	4.01	56.09
Temp Summer	0.813	0.038	0.000	4.28	72.06
Temp Fall	0.759	0.039	0.000	4.05	58.99
Temp Winter	0.761	0.039	0.000	3.72	42.80
Prec	-0.002	0.002	0.384	-0.66	1.14
Cons Spring	-0.029	0.002	0.000	n/a	4.20
Cons Summer	-0.026	0.002	0.000	n/a	4.00
Cons Fall	-0.014	0.002	0.000	n/a	4.33
Cons Winter	-0.020	0.003	0.000	n/a	4.31

† Mean values across all cities for the period January 1984 through April 1994.

calculated by a series of steps). Summer price elasticity for the region is estimated to be −0.23; spring price elasticity is estimated to be −0.13; and fall price elasticity is estimated to be −0.18. The winter elasticity estimate has an unexpected positive value of 0.02 but is statistically insignificant or no different than zero. If statistically significant, this response could be an indication that consumers may be aware that their winter use defines the base quantity (such as Albuquerque) on

Table 4.6
Regional season specific model price elasticity estimates and effect of price increase

	Spring	Summer	Fall	Winter	Seasonal Avg.
Monthly bill 1995$	21.50	33.00	23.00	17.00	23.63
10% increase in marginal price $	23.15	35.80	24.80	18.20	25.49
Use/acct. (1,000 gallons/month)	11.00	18.00	12.00	8.00	12.25
Use/acct. after price change	10.86	17.58	11.78	8.02	12.06
Elasticity	-0.13	-0.23	-0.18	0.02	-0.15

which summer use is priced. The traditional negative price elasticity is highest during the summer months (-0.23).

Table 4.6 illustrates the impact on water use and residential monthly water bill on a seasonal basis for a 10 percent increase in the marginal water price. The rate structure incorporated in the elasticity estimates is the same as in Table 4.2. The monthly bill associated with this rate structure and use patterns by season is indicated in row one. The last rows of Table 4.6 indicates the estimated change in water use per account predicted by the Season Specific model and the associated water price elasticity holding all other variables constant.

Test for Consumer Price Perception Under the Season Specific Model

Season Specific model results of the Shin price perception test vary according to season. Consumers appear to respond to the average price during the summer (the value of Shin test statistic, $k =$ 0.84 and is not statistically different from one), marginal price during the fall ($k = 0.01$ and is not significantly different than zero) and to some combination of average and marginal price during the spring ($k = 0.62$ and is statistically different from one) and winter ($k = 0.48$ and is statistically different from one). As indicated, these results are mixed suggesting consumers respond differently depending upon the season. But given the general price inelasticity of demand, consumer perceptions may not be that relevant in that there is a very low response to increases in either the average or marginal price.

Nonprice Conservation Effectiveness Under the Season Specific Model

Estimates of nonprice conservation program effectiveness are statistically significant and vary by season (*Cons* = -0.029, -0.026, -0.014 and -0.2 for spring, summer, fall and winter, respectively) indicating that nonprice programs are effective in reducing residential water use. Nonprice conservation efforts are *most* effective during the spring and summer seasons. Water use reduction is estimated to be between 1.4 and 2.9 percent of total demand per program depending on the season. Effectiveness of conservation programs averaged a 2.2% decrease. Because the information regarding nonprice programs is incomplete, the model and this parameter are not able to distinguish individual types or specific programs nor estimate the residual or lasting effects of nonprice programs.

Predictive Capability of the Season Specific Model

The Season Specific model was estimated using maximum likelihood regression techniques, therefore there is no "goodness of fit" measure such as R^2, (the likelihood value is difficult to interpret). However, it is possible to compare predicted estimates to actual use values using the following simple linear regression model:

$$Actual_t = b_0 + b_1\ (predicted_t) \qquad (4.1)$$

where $actual_t$ is the observed water use per month for all seven cities, and $predicted_t$ is the predicted water use of the Season Specific model applied to the database (often called sample prediction or

Table 4.7
Regression results (predicted vs actual) of seasonal model

Regression Output	
R Squared	0.973
No. of Observations	945
Degrees of Freedom	943
Beta Coefficient (b_1)	1.1114
Std. error of (b_1)	0.0190
Constant (b_0)	74,463

forecast). Table 4.7 illustrates the predictive capabilities of the Season Specific model, again using the linear regression model:

The Season Specific model attempts to explain the seasonal water use relationships and patterns, again across all seven cities. The R_2 regression results of predicted versus actual water demand is slightly higher (97 percent) which is also confirmed by subsequent maximum likelihood tests conducted later in this chapter. The Season Specific model does exhibit more bias, underestimating actual water demand by approximately 11 percent ($b_1 = 1.11$). In applying estimates of the Season Specific and other models to make predictions the best (most reliable) results will be obtained by using variable values near the average and within the range of variable observations. Table 4.8 outlines the range in average and marginal prices and number of conservation programs that are implicit in the Season Specific model estimates. Again, the best predictions would be near the regional average value for each variable.

Table 4.8
Seasonal model price coefficient relevant data ranges
(prices in 1995$ per thousand gallons)

Variable	Maximum	Minimum	Average
Spring			
Average Price	5.57	1.01	2.08
Marginal Price	4.98	0.57	1.73
Conservation programs (#)	15	0	4.2
Summer			
Average Price	5.57	1.01	2.08
Marginal Price	4.93	0.76	1.71
Conservation programs (#)	15	0	4.2
Fall			
Average Price	5.52	1.01	1.97
Marginal Price	5.03	0.77	1.71
Conservation programs (#)	15	0	4.2
Winter			
Average Price	5.82	1.14	2.25
Marginal Price	5.00	0.54	1.72
Conservation programs (#)	15	0	4.2

Figure 4.2 illustrates the predictive capabilities of the Season Specific model comparing predicted use against actual residential use in each city. Each vertical grid of the graph represents the start of the time series for a specific city (labeled along the bottom of the graph). The graph illustrates a twelve month moving average or long-term trend in water demand for each of the seven cities. As with the Regional model, the Season Specific model under predicts Los Angeles and Denver. The model however better accounts for average use differences between cities, possibly because water price elasticity is more flexibly defined.

The Season Specific model provides the next most general estimates of water demand relationships, and in the absence of specific city information the model results should prove useful in estimating seasonal and total water demand and influences in other cities in the region.

CITY/SEASON SPECIFIC MODEL

The City/Season Specific model disaggregates price, temperature and nonprice conservation variables according to season and individual city. Water demand relationships (variable coefficients) are estimated for each city for each season. The City/Season Specific model is a not a regional model; the coefficients are estimated based on the separate individual observations of each city. The City/Season Model is formulated as follows:

$$\ln(Q_t) = b_0 + \Sigma_{I=1..4}\,[b_{1i}\ln(MP_{it}) + b_{2i}\ln(AP/MP_{it})] + b_3\ln(INC_t) + \Sigma_{I=1..4}\, b_{4i}\ln(TEMP_{it}) + b_5\ln(PREC_{it}) + b_6\ln(ACCT_t) + \Sigma_{I=1..4}\, b_{7i}(CONS_{it}) + b_8(Drought_t) + b_9(Time) + M \quad (2.7)$$

where the following is the list of variable names and definitions:

1. Q_t = total city monthly residential water quantity consumed at time t;
2. MP_t = marginal price per 1,000 gallons defined on a seasonal and city basis, (the variable has the observed value for the appropriate season and city, zero otherwise);
3. AP/MP_t = ratio of average price to marginal price defined on a seasonal and city basis, (the variable has the observed value for the appropriate season and city, zero otherwise);

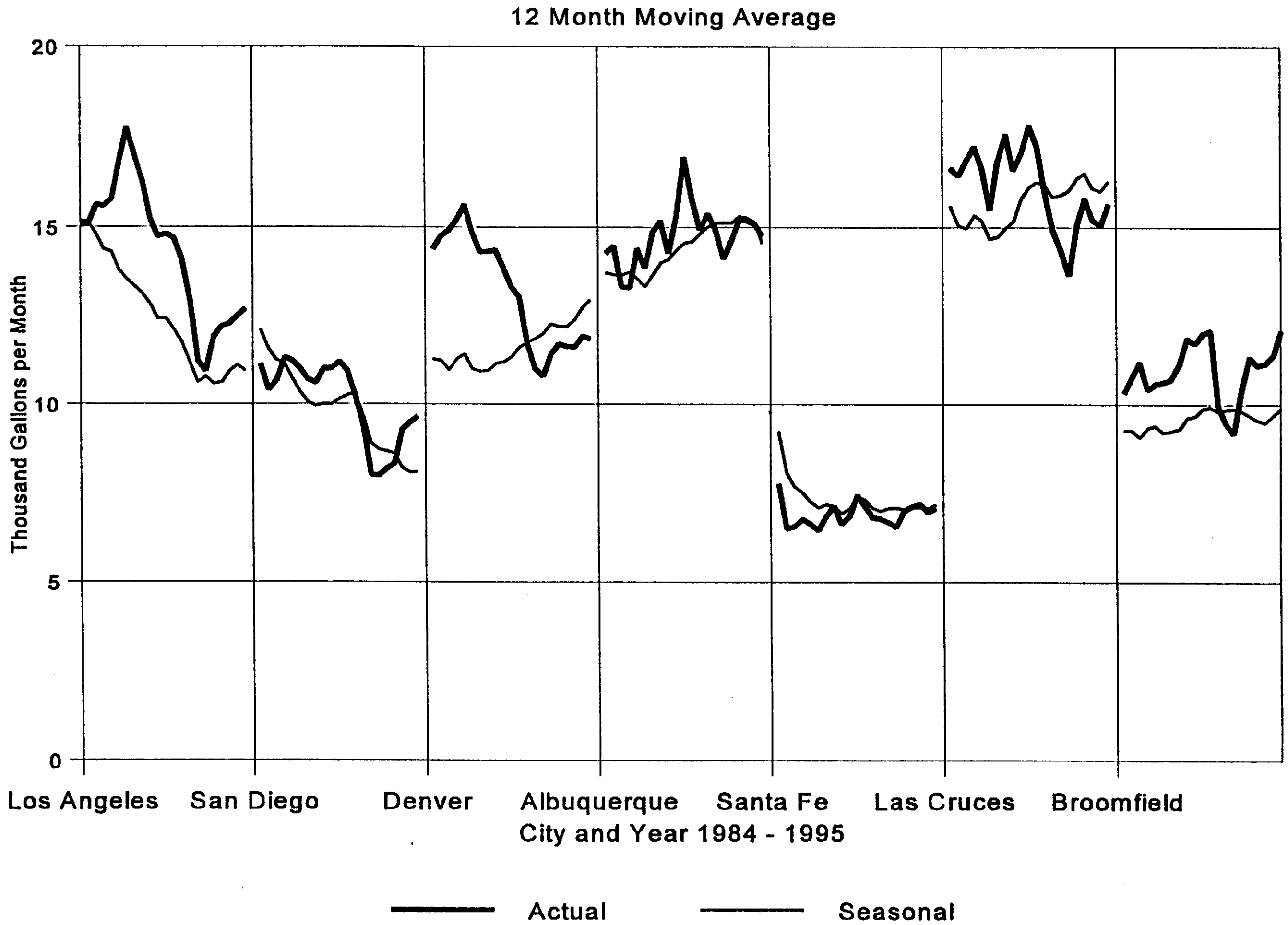


Figure 4.2 Seasonal model predicted and actual water use

4. INC_t = average monthly household income for that city;

5. $TEMP_t$ = average monthly temperature defined on a city basis, (the variable has the observed value for the appropriate city, zero otherwise);

6. $PREC_t$ = total monthly precipitation;

7. $ACCT_t$ = number of single-family residential accounts for that month and city;

8. *CONS* = number of conservation programs defined on a seasonal and city basis, (the variable has the observed value for the appropriate season and city, zero otherwise);

9. *Drought* = binary variable for drought conditions in southern California during January 1991 through March 1993;

10. *Time* = time, year and month on a fractional year basis;

11. *M* = normally distributed error.

12. b1 ..b9 are coefficients to be estimated, referred to as "betas."

13. The index (i) refers to season and city combinations (4 seasons, 7 cities, a total of 28 combinations.

Due to the great number of coefficient values estimated under the City/Season Specific model we limit our discussion to price and nonprice program effectiveness.

Price Responsiveness Under the City/Season Specific Model

The City/Season Specific model estimates of the price elasticity of water demand vary widely between cities with season average elasticities ranging from -0.37 in Albuquerque to -0.02 in Denver and 0.05 in San Diego. Price elasticity estimates by city and season are presented in Table 4.9. Table 4.9 also illustrates the impact on water use and residential monthly water bills by individual city on a seasonal basis for a 10 percent increase in the marginal water price.

Due to the structure of the City/Season Specific model, all cross-city price variation is eliminated. Price fluctuations (or the lack of them) within an individual city, greatly influence their respective elasticity estimates. In other words, if a city's average and/or marginal price did not change significantly (as measured in inflationary adjusted terms over the time series analyzed), a reliable responsiveness level cannot be determined.

Table 4.9
Seasonal elasticity estimates and response to a ten percent increase in price

City	Spring	Summer	Fall	Winter	Year Avg.
LOS ANGELES					
Monthly bill 1995$	31.00	43.20	36.03	26.95	34.29
10% increase in marginal price $	34.10	47.52	39.63	29.65	37.72
Use/acct. (1,000 gal./month)	12.40	17.28	14.41	10.78	13.72
Use/acct. after price change	12.31	17.03	14.41	10.61	13.59
Elasticity	-0.07	-0.14	0.00	-0.15	-0.09
SAN DIEGO					
Monthly bill 1995$	18.98	25.01	22.95	17.15	21.02
10% increase in marginal price $	20.57	27.20	24.94	18.55	22.81
Use/acct. (1,000 gal./month)	9.01	12.17	11.09	8.05	10.08
Use/acct. after price change	9.01	12.17	11.09	8.26	10.13
Elasticity	0.00	0.00	0.00	0.27	0.05
DENVER					
Monthly bill 1995$	16.19	32.18	18.64	10.97	19.49
10% increase in marginal price $	17.44	35.03	20.13	11.70	21.08
Use/acct. (1,000 gal./month)	11.50	23.90	13.40	6.77	13.89
Use/acct. after price change	11.50	23.78	13.40	6.77	13.86
Elasticity	0.00	-0.05	0.00	0.00	-0.02
BROOMFIELD					
Monthly bill 1995$	24.66	37.93	24.72	18.10	26.35
10% increase in marginal price $	26.54	41.14	26.60	19.32	28.40
Use/acct. (1,000 gal./month)	10.00	17.06	10.03	6.51	10.90
Use/acct. after price change	8.84	17.06	10.03	6.67	10.65
Elasticity	-1.16	0.00	0.00	0.24	-0.23
ALBUQUERQUE					
Monthly bill 1995$	17.13	27.24	18.27	12.17	18.70
10% increase in marginal price $	18.35	29.48	19.61	12.90	20.09
Use/acct. (1,000 gal./month)	13.50	22.70	14.76	8.05	14.75
Use/acct. after price change	13.50	22.43	12.85	8.05	14.21
Elasticity	0.00	-0.12	-1.29	0.00	-0.37
SANTA FE					
Monthly bill 1995$	26.14	36.99	28.59	22.92	28.66
10% increase in marginal price $	28.06	40.00	30.76	24.52	30.83
Use/acct. (1,000 gal./month)	6.20	9.30	6.90	5.28	6.92
Use/acct. after price change	6.20	9.30	6.90	5.37	6.94
Elasticity	0.00	0.00	0.00	0.17	0.03
LAS CRUCES					
Monthly bill 1995$	14.84	20.64	14.47	11.06	15.25
10% increase in marginal price $	15.81	22.19	15.40	11.66	16.29
Use/acct. (1,000 gal./month)	15.80	25.00	15.20	9.80	16.45
Use/acct. after price change	15.80	23.98	15.20	10.33	16.33
Elasticity	0.00	-0.41	0.00	0.54	-0.07

Note: = Monthly bill based on April 1995 rates. Seasonal average is a weighted quantity.

Table 4.10
Changes in average price, marginal price and water use: 1984-1994 (values in 1995$)

City	*AP $	*MP $	*Use/Acct (1,000 gal/month)
LOS ANGELES			
1994	2.44	2.44	12.64
1984	1.70	1.28	15.27
Change between 84 and 94	44%	91%	- 17%
SAN DIEGO			
1994	2.12	1.96	9.29
1984	1.66	1.49	11.13
Change between 84 and 94	28%	32%	-8%
DENVER			
1994	1.27	1.23	12.63
1984	1.40	0.86	14.40
Change between 84 and 94	9%	8%	-12%
BROOMFIELD			
1994	2.46	1.93	12.10
1984	2.38	2.09	10.33
Change between 84 and 94	3%	- 8%	17%
ALBUQUERQUE			
1994	1.25	0.81	14.76
1984	1.42	0.91	14.29
Change between 84 and 94	-14%	-11%	-3%
SANTA FE			
1994	4.00	3.51	7.06
1984	3.48	2.97	6.67
Change between 84 and 94	15%	18%	6%
LAS CRUCES			
1994	1.16	0.98	15.67
1984	1.19	0.97	16.64
Change between 84 and 94	- 3%	1%	- 6%

Note: Prices are in constant (real) 1995$. Water use and change in use per account are unadjusted for climate conditions, nonprice conservation programs or other factors. * denotes annual average values.

Several study area cities had relatively little change in real prices. Table 4.10 indicates the change in average and marginal price between 1984 and 1994. (Average price and marginal price were calculated based on corresponding monthly use levels.) The values listed in Table 4.10 represent the annual average for both average price and marginal price. Use per account values also indicate annual average monthly use levels.) Note that for Albuquerque, Las Cruces, Broomfield and Denver there is very little real price change between 1984 to 1994, less than $0.16 per 1,000 gallons or, in terms of average bill, less that $2.50 (calculated based on a average annual use level of 15,000 gallons). Santa Fe, San Diego and Los Angeles had real price increases of $0.47 or more. Of these three cities, Santa Fe use did not significantly change, but note that Santa Fe already had relatively high water rates in 1984 and already had low water use patterns. To summarize, the City/Season Specific model is limited in the range of price predictions that can be made. It would be inappropriate to predict price effects outside the 1984 - 1994 data range for any of the seven cities.

Nonprice Conservation Program Effectiveness

Cities that have a substantial number of nonprice conservation programs over the period analyzed have been able to reduce residential water use levels. Table 4.11 presents the City/Season Specific model estimates of nonprice conservation program effectiveness by individual city and season. As noted above, the limited variation of observations, in this case within a single city, restricts the predictive capability of the model concerning conservation programs. It is important to remember that these results are not general (for the region), but are based on single city observations. The relevant data range of conservation programs for each city is indicated in the last column. In some situations the number of conservation programs that have been implemented may be misleading. For example, in Albuquerque there were only 13 monthly observations of nonprice conservation efforts because program efforts only began in June of 1994. It will be necessary to examine longer time periods of conservation efforts before a reliable conclusion can be reached for Albuquerque. Consumer responsiveness to nonprice programs was also estimated to be zero in Santa Fe. Although Santa Fe has had programs in effect as early as 1988, there have been a relatively small number of programs. It must be noted, however, that Santa Fe has successfully achieved significant levels of water conservation through their pricing efforts. Las Cruces and Broomfield did not implement nonprice conservation programs over the period of analysis.

Predictive Capability of the City/Season Specific Model

The City/Season Specific model was estimated using maximum likelihood regression techniques, therefore there is no "goodness of fit" measure such as R^2, (the likelihood value is difficult to interpret). However, it is possible to compare predicted estimates to actual use values using the following simple linear regression model:

$$Actual_t = b_0 + b_1 (predicted_t) \qquad (4.1)$$

where $actual_t$ is the observed water use per month for all seven cities, and $predicted_t$ is the predicted water use of the City/Season Specific model applied to the database (often called sample prediction or forecast). Table 4.12 illustrates the predictive capabilities of the City/Season Specific model, again using the linear regression model:

The City/Season Specific model predicted versus actual water demand regression has a very high R^2 of almost 99 percent. More significantly, the regression indicates no bias in City/Season Specific model water demand prediction. The beta coefficient is statistically equal to one indicating the model does not over or underestimate actual values. This is good in terms of modeling within the observed range of variable values for a specific city. A major limitation of the City/Season Specific

Table 4.11

Nonprice conservation program effectiveness on a seasonal basis by city

(estimated average percent per program change in water demand)

	Winter	Spring	Summer	Fall	Year (season avg.)	No. of Nonprice Pgms.† (Relevant Range)
Los Angeles	- 3.5	- 5.2	- 3.2	- 4.4	- 3.9 ††	6-14
San Diego	- 1.4	- 3.6	- 4.7	- 2.1	- 2.7 ††	6-15
Denver	- 3.1	-3.6	0.0	- 1.7	- 2.1	5-13
Broomfield	0.0	0.0	0.0	0.0	0.0	0
Albuquerque	0.0	0.0	0.0	0.0	0.0	0-6
Santa Fe	0.0	0.0	0.0	0.0	0.0	0-4
Las Cruces	0.0	0.0	0.0	0.0	0.0	0

† Range in the number of concurrent conservation programs during the period from January 1984 through April 1995.
†† For Los Angeles and San Diego, the increase in number of conservation programs occurred immediately prior to the drought period, possibly masking the drought effect.

Table 4.12
Regression results (predicted vs actual) of city/season specific model

Regression Output	
R Squared	0.989
No. of Observations	945
Degrees of Freedom	943
Beta Coefficient (b_1)	1.002
Std. error (b_1)	0.004
Constant (b_0)	-10,487

model are the more restrictive data ranges for each city in price and nonprice programs that have been discussed above.

Figure 4.3 illustrates the predictive capabilities of the City/Season Specific model comparing predicted use against actual residential use in each city. Each vertical grid of the graph represents the start of the time series for a specific city (labeled along the bottom of the graph). The graph illustrates a twelve month moving average or long-term trend in water demand for each of the seven cities. The model is accurate in all cities. The City/Season Specific model provides the most specific predictions but the least general information regarding water demand relationships over a variety of conditions and for different cities in the region.

LEVEL OF AGGREGATION

A fundamental issue is whether the variables and relationships that affect residential water demand vary from city to city or are similar in different cities across the study area. That is, do residential water consumers in Los Angeles and consumers in Denver respond similarly to changes in water price and to the implementation of nonprice conservation programs? The most general model of demand is the Regional model. The estimated coefficients, such as demand elasticity have the same values for different cities and over time. This model is conceptually the simplest (one model fits all) and the findings, if valid and significant, could be extended to other southwestern cities. However, the Regional model may *not* be appropriate for urban water demand estimation. The implicit assumption in the Regional model is that residential water users have similar habits between cities and over time (year-round). If this assumption is inappropriate, then more specific formulations are necessary that allow for coefficient changes over time and/or between cities.

To test the appropriateness of using a particular model, we statistically compare all three models, the Regional (1), Season Specific (2), and the City/Season Specific (3). The Regional model uses the pooled observations in all of the cities and because of its generality constrains all of the water demand coefficients to be equal across the seven cities. The Season Specific model is somewhat less general and restricts price and nonprice conservation coefficients to the variations observed within each season but still across all cities. The distinction between the Season Specific model and the City/Season Specific model is that the latter allows both the price and nonprice conservation coefficients to vary across both seasons and individual cities. The City/Season Specific model is the most focused on the experience of individual cities, but has the least generality. Because of the larger number of explanatory variables, the City/Season Specific model will best predict use patterns for an individual city. The Regional and Season Specific models are more restrictive structures but the results are more generally applicable to other cities. One important issue that is examined is whether the restrictions placed by the Season Specific and Regional models (constant price, nonprice conservation program and other coefficients) bias the estimated results.

A likelihood ratio test is used to examine the similarity between the Regional and Season Specific models and help identify appropriate use of the three models (Green, pg. 129). The City/Season Specific model has the highest log likelihood value (L = 801), an index of the statistical fit of the model. The Season Specific model has a log likelihood value of L = 664, and the Regional model has a log likelihood value of L = 617. The likelihood ratio test determines whether the predictive power of the City/Season Specific model is significantly reduced by the restrictions imposed by the Regional and Season Specific models. The null hypothesis is that the predictive ability of the Regional and Season Specific models are statistically the same as the City/Season Specific model as measured by the log likelihood value (model 3 = model 1 and model 3 = model 2). Results are indicated in Table 4.13.

Table 4.13

Log likelihood comparisons and test for differences in models

Test	Unrestricted Log Likelihood	Restricted Log Likelihood	Test Statistic	Critical Value (Chi)	Accept/Reject Ho
Ho: 3 = 1	801	617	368	27.1	Reject
Ho: 3 = 2	801	664	264	4.07	Reject

Note: Comparison of City/Season Specific Model (3) to Regional (1) and Season Specfic (2) models.

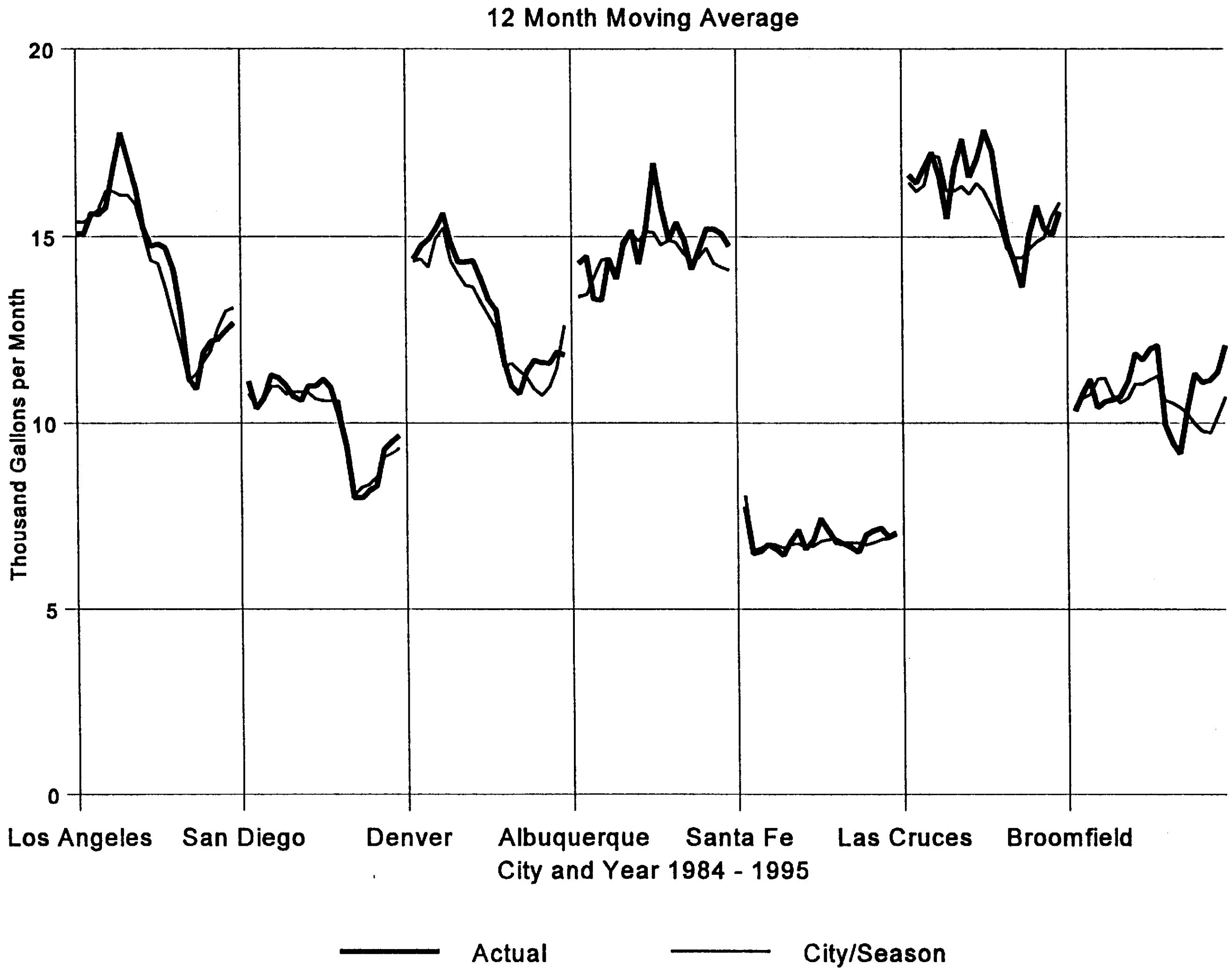


Figure 4.3 City/seasonal model predicted and actual water use

The likelihood tests of the City/Season Specific model (3), relative to the Regional model (1) and Season Specific model (2), indicate that there is too large a change in the value of the likelihood ratio statistic to accept the more general models as having the same predictive power as the City/Season Specific model. Thus, the City/Season Specific model contains the least statistical error.

This finding does not make the City/Season Specific model the "best" model. A disadvantage of the City/Season Specific model is that it provides less reliable predictions outside the range of historical data for any given city. For example, the City/Season Specific model may accurately predict water use in Denver over the past 10 years. But what if Denver were to impose a water rate structure similar to Los Angeles? This pricing scheme is outside the bounds of Denver's pricing experience, and thus the City/ Season Specific model would be less reliable in predicting Denver's water use under these circumstances. There is a trade-off between statistical accuracy and generality of the three model predictions. This trade-off is more fully discussed in the following sections discussing the results of each of the three models.

ACTUAL VERSUS PREDICTED WATER DEMAND

Actual residential water demand and predicted total water demand from the results of the three regression models are illustrated by city. Figures 4.4 through 4.10 show actual and predicted water use per household on a one month interval for each of the seven cities. The dominant feature of all residential water use patterns in the southwestern United States is the summer peak and winter trough. There are also large variations in monthly and seasonal water demand within individual cities. The models are not uniform in their ability to capture these seasonal variations in each city. As illustrated by the figures, the City/Season Specific model is able to predict trends in water use over time for different cities in the southwestern United States. Although the Seasonal model is consistent in accurately capturing winter time use in all cities, it is somewhat less reliable in capturing all of the summer peak use in each city. The City/Season Specific Model is the most accurate in predicting individual city water use.

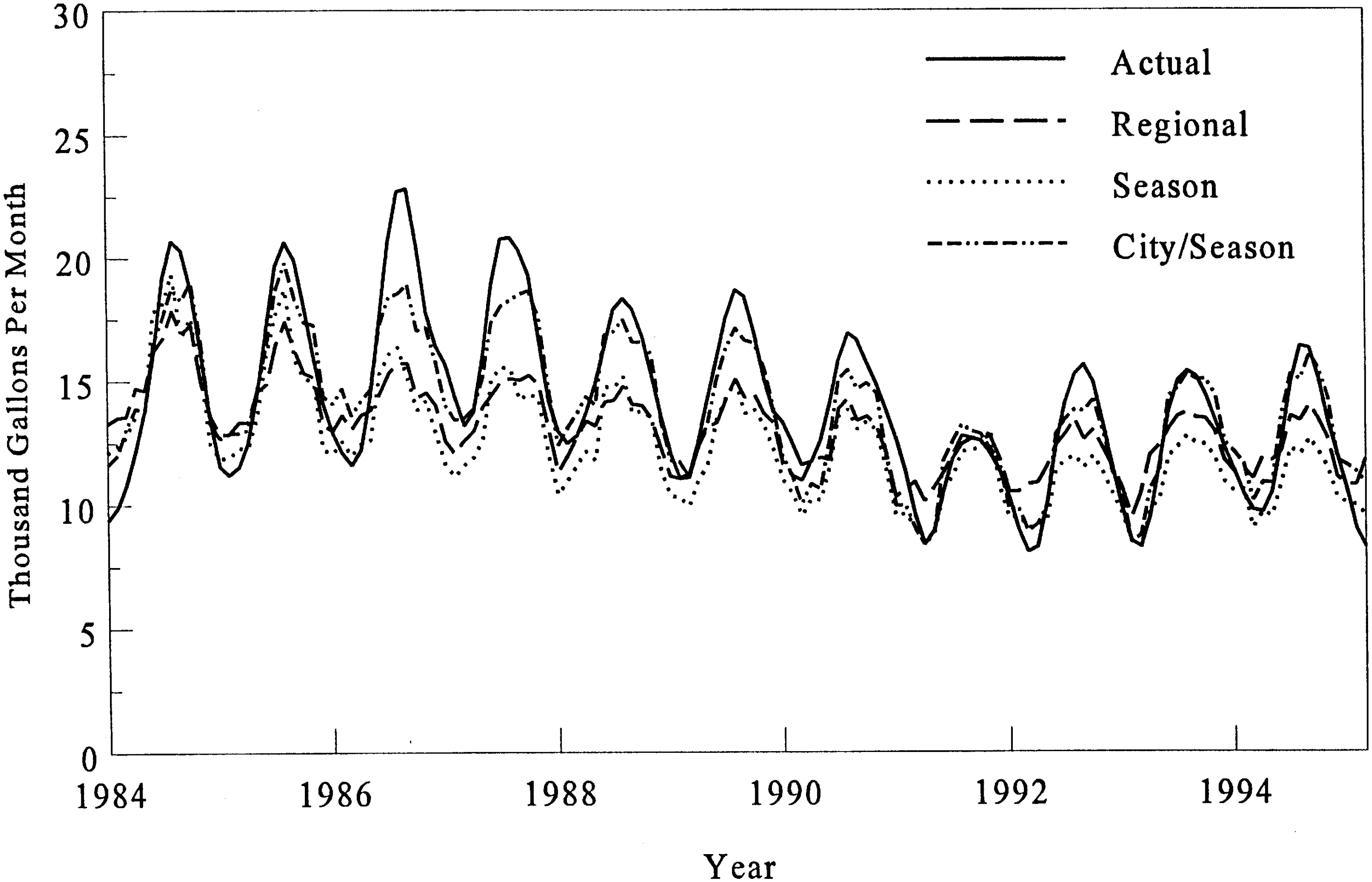


Figure 4.4 Los Angeles predicted versus actual household water use

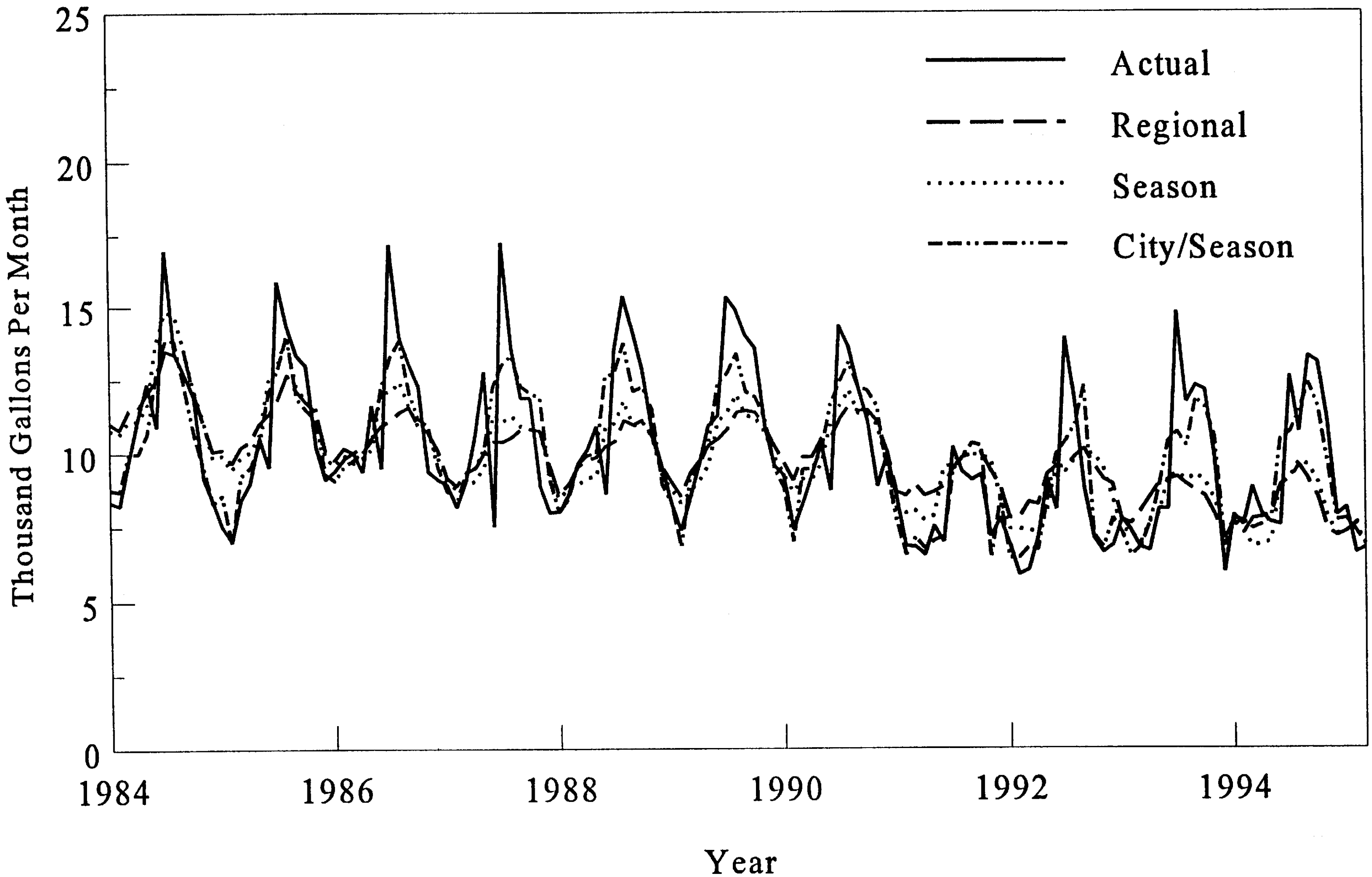


Figure 4.5 San Diego predicted versus actual household water use

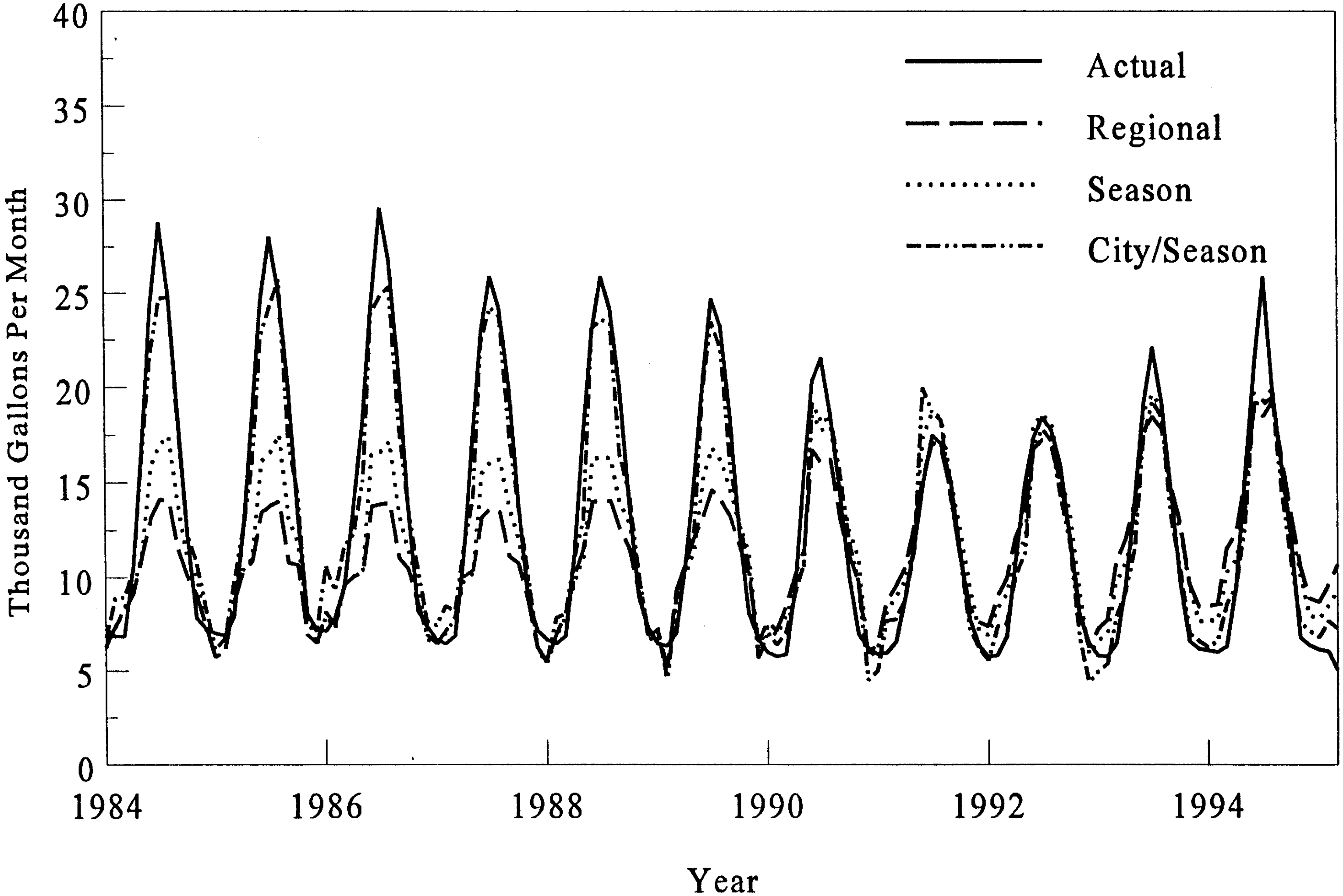


Figure 4.6 Denver predicted versus actual household water use

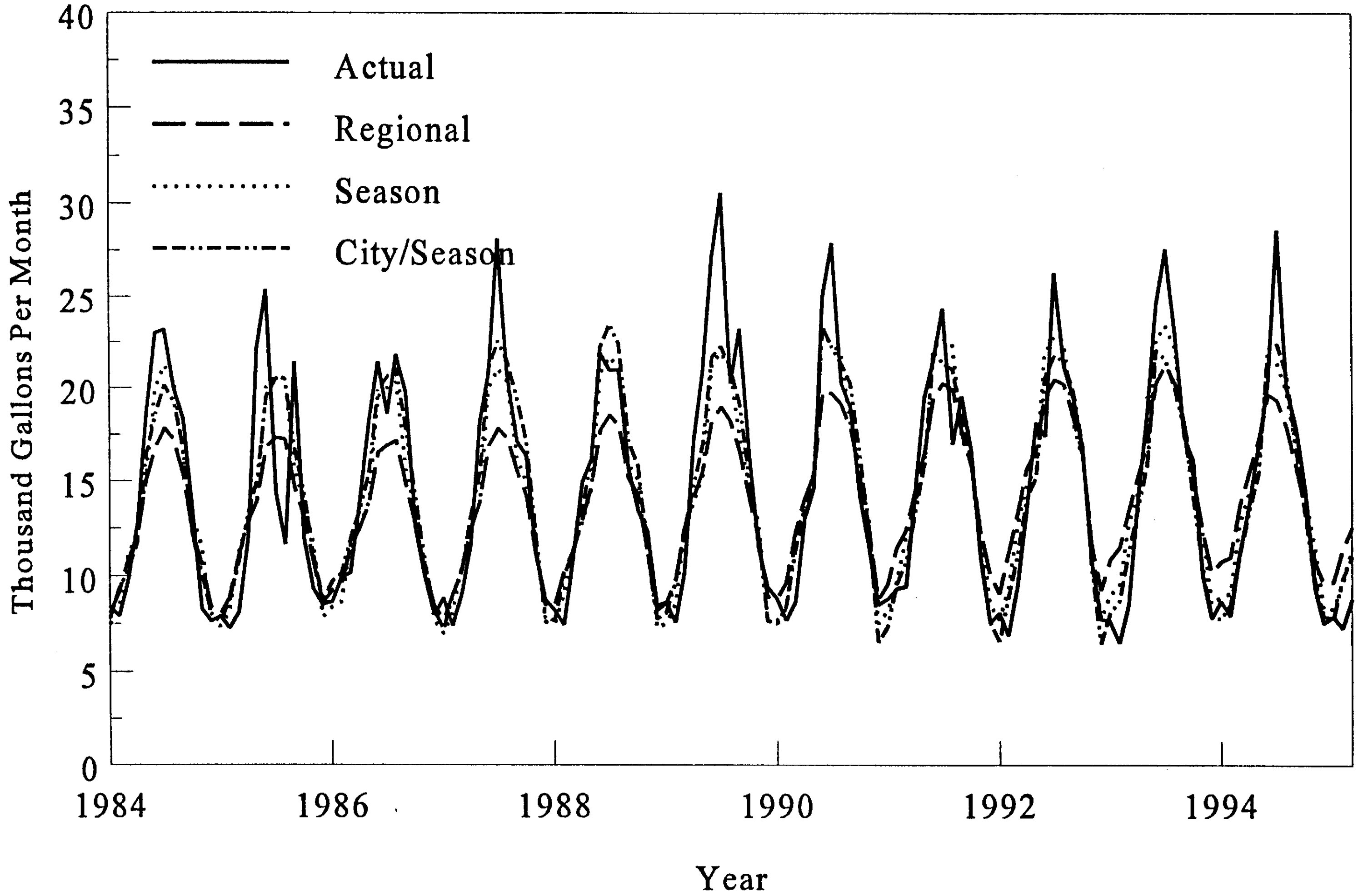


Figure 4.7 Broomfield predicted versus actual household water use

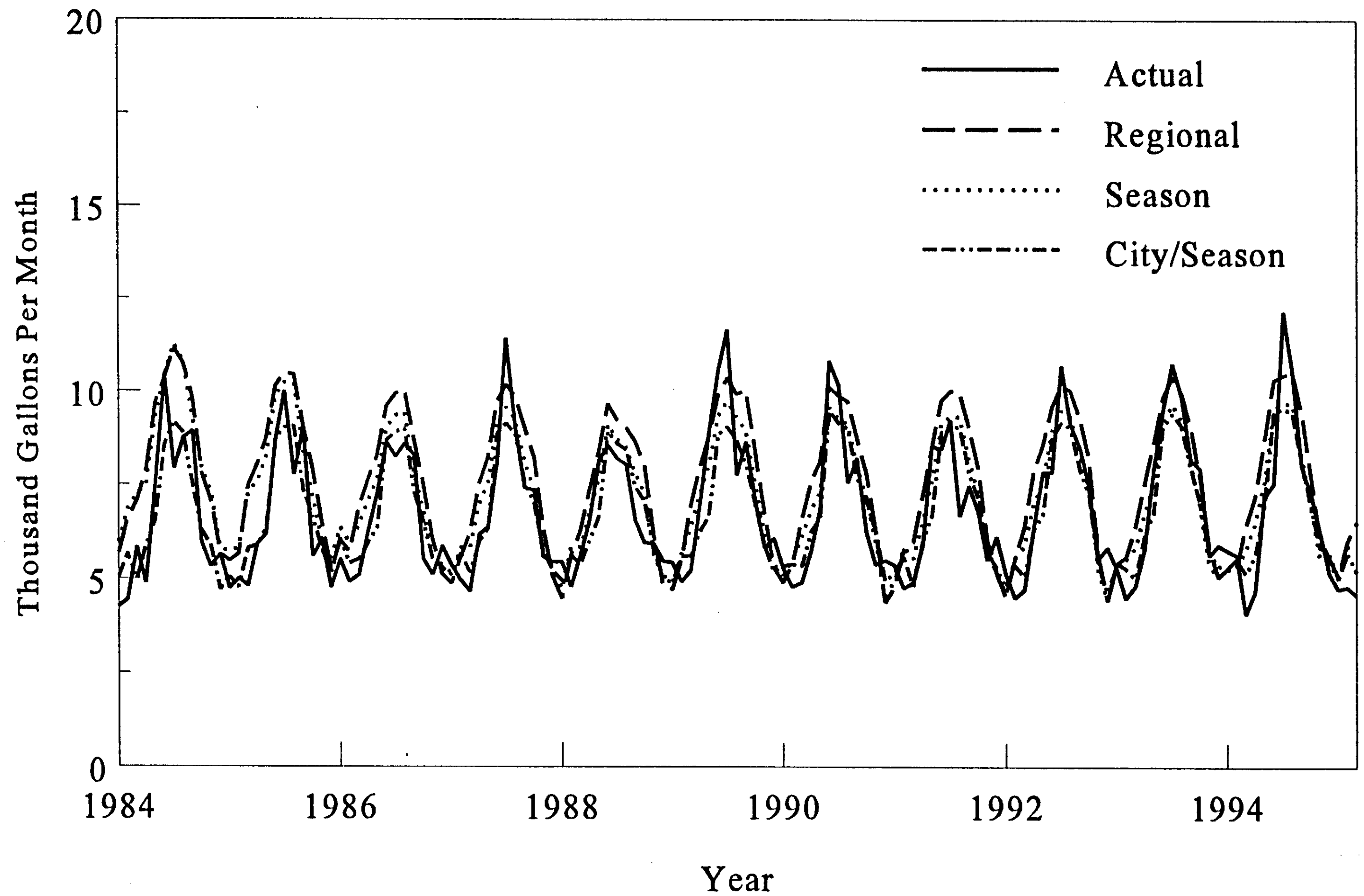


Figure 4.8 Albuquerque predicted versus actual household water use

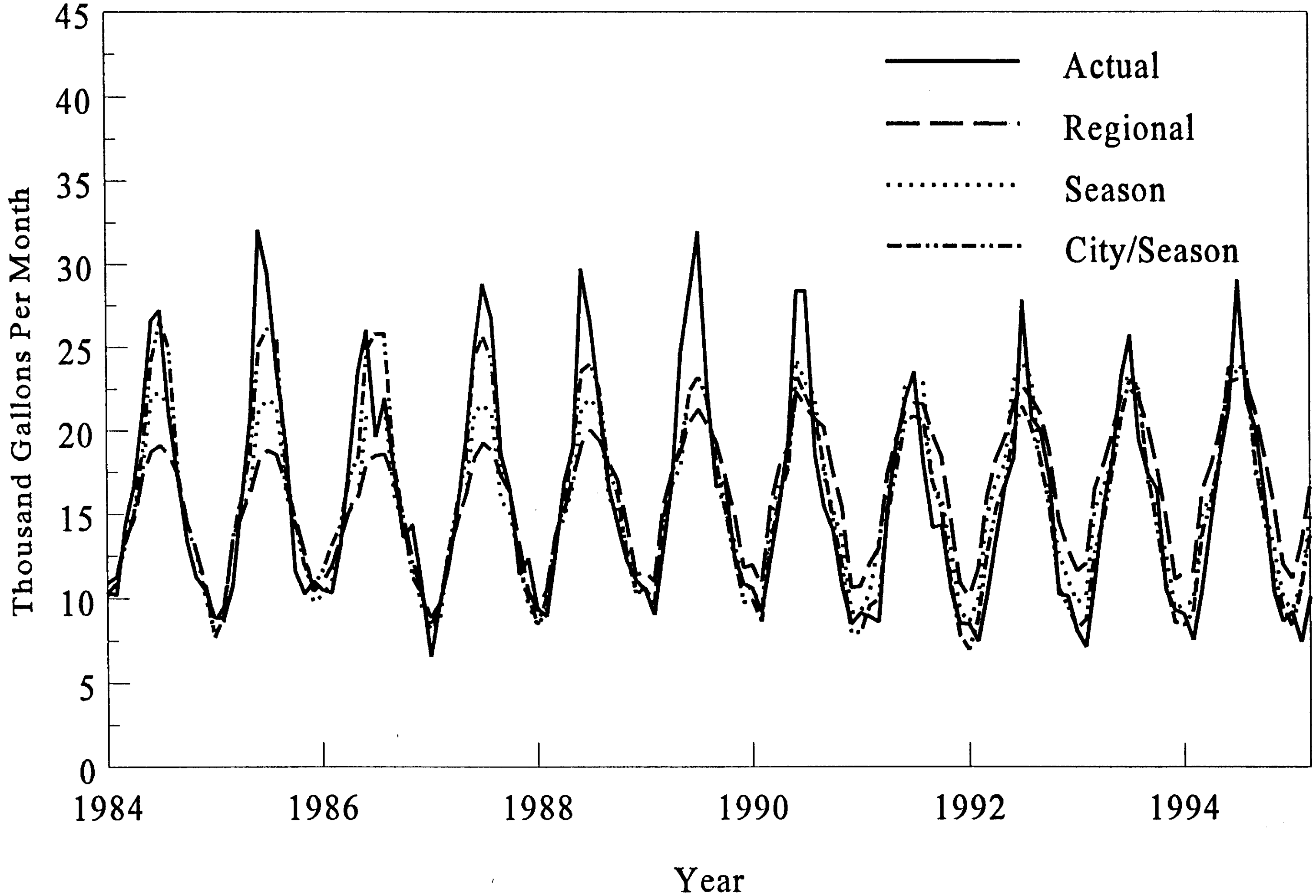


Figure 4.9 Las Cruces predicted versus actual household water use

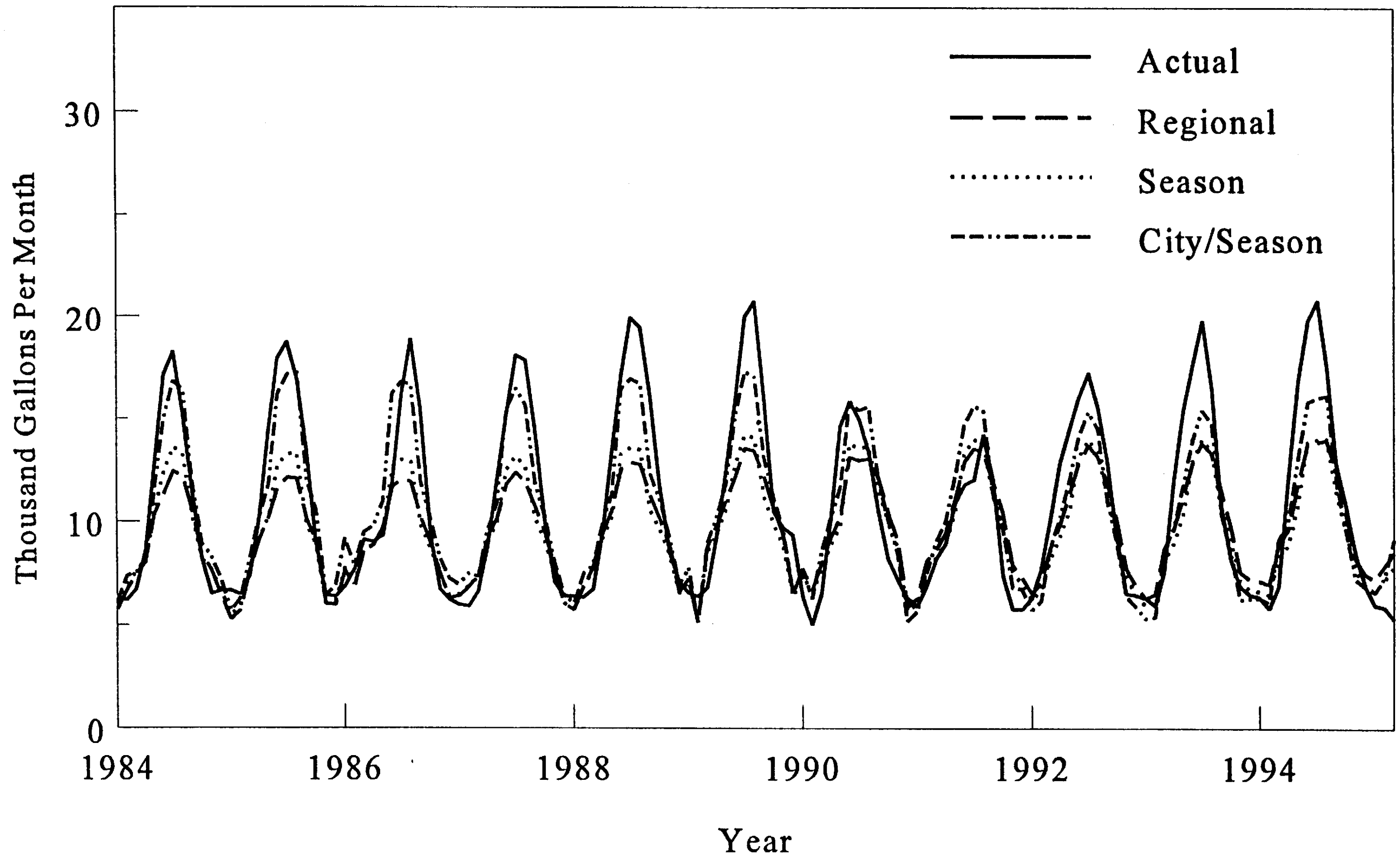


Figure 4.10 Santa Fe predicted versus actual household water use

ALTERNATIVE DEMAND MODEL FORMULATION

An alternative model functional form is used to estimate regional, seasonal and individual city water demand and test for robustness of the original models and coefficient results. The functional form of demand underlying the Regional, Season Specific and City/Season Specific models is multiplicative. This form accounts for interactions between average and marginal price and other variable effects on demand. Different water demand model formulations were also tested and the results are reported here. The most direct alternative functional form is a linear specification outlined below for the regional model:

$$q_t = b_0 + b_1 (MP_t) + b_2 (INC_t) + b_3 (TEMP_t) + b_4 (PREC_t) + b_5 (ACCT_t) + b_7 (CONS_t) + b_8 (Drought_t) + b_9 (Time_t) + M \quad (4.2)$$

where the following is the list of variable names and definitions (values in 1995$):

1. q_t = monthly residential water quantity per account consumed at time t;
2. MP_t = marginal price per 1,000 gallons, the price appropriate for the average consumption in the city for that month;
3. INC_t = average monthly household income for that city;
4. $TEMP_t$ = average monthly temperature;
5. $PREC_t$ = total monthly precipitation;
6. $ACCT_t$ = number of single-family residential accounts for that month and city;
7. *CONS* = number of conservation programs in effect;
8. *Drought* = binary variable for drought conditions in southern California during January 1991 through March 1993;
9. *Time* = time, year and month on a fractional year basis;
10. *M* = normally distributed error;
11. b1 .. b9 are coefficients to be estimated, referred to as "betas."

There are several differences in the linear model. Total city use is a product of residential use per account times the number of accounts. A linear model can not incorporate this multiplication and the dependant use variable must be specified on a per account basis (as opposed to total city use in previous multiplicative models). Likewise, the Shin average price/marginal price specification (equation 2.5) is multiplicative and can not be incorporated into a linear model. For the linear estimation, consistent with traditional economic theory, only the marginal price is used. With these exceptions, linear demand equations were formulated for Regional, Season Specific and City/Season Specific models, and results are briefly reviewed here.

Empirical results of the linear functional form demand models are remarkably similar to the results of the multiplicative form models. The linear models also have the same aggregation problems. The City/Season Specific model best explains the data but has the least generality. Comparison of predictive accuracy (fit of predicted against actual use) for linear models indicates that the linear formulations have approximately the same accuracy as the multiplicative models (the linear is slightly less accurate). Finally the interpretation of results is almost identical. The linear models result in the same price elasticity and estimates of nonprice conservation effectiveness. To illustrate this we compare the linear to multiplicative formulation for the Season Specific model below. The estimated regression coefficients for the linear model (season) are indicated in Table 4.14.

Price and nonprice conservation program coefficients are significant and have the expected negative values. Precipitation (*Prec* = 0.011) is positive but insignificant. Time (*Time* = 0.194) is positive and significant. One of the few differences between the multiplicative and alternative model parameter results is the variable for drought in California which is negative and significant (*Drought* = -1.657). (Note that the parameter values of the linear are different from the multiplicative form because of the different functional forms and are not directly comparable). Overall, the results of the linear model are almost identical to the results obtained with multiplicative model (see Table 4.5). The price elasticities of demand are the same for the linear model and multiplicative models as shown in Table 4.5.

For illustrative purposes, Table 4.15 indicates seasonal and annual response to a 10 percent increase in marginal price for the linear and multiplicative models. Price elasticities of demand in the linear equation are calculated by measuring the estimated change in residential use as marginal price increases. The calculation of price elasticity proceeds in steps: (1) current water use is the baseof reference; (2) beginning with the marginal price for the appropriate block of current use new marginal prices are calculated for a 10 percent increase; (3) new marginal prices are entered into the

Table 4.14

Linear formulation season specific model results

Variable	Coefficient	Standard Error	Probability that the coefficient is not significant	Mean Linear Value †
Constant	-371.67	79.859	0.000	n/a
Acct	0.0000087	0.0000011	0.000	114,549
MP Spring	-1.116	0.116	0.000	1.71
MP Summer	-2.319	0.122	0.000	1.75
MP Fall	-1.140	0.116	0.000	1.75
MP Winter	-0.243	0.117	0.038	1.66
Drought	-1.657	0.419	0.000	n/a
Time	0.194	0.009	0.000	n/a
Income	-0.00036	0.000038	0.000	32,875
Temp Spring	0.187	0.010	0.000	56.09
Temp Summer	0.254	0.009	0.000	72.06
Temp Fall	0.193	0.009	0.000	58.99
Temp Winter	0.141	0.011	0.000	42.80
Prec	0.011	0.037	0.772	1.14
Cons Spring	-0.218	0.038	0.000	4.20
Cons Summer	-0.276	0.041	0.000	4.00
Cons Fall	-0.125	0.038	0.000	4.33
Cons Winter	-0.044	0.038	0.256	4.31

† Mean values across all cities for the period covering January 1984 through April 1994.

regression equation to derive the new water use; and (4) the change in water use is calculated on a percentage basis and divided by the 10 percent price increase to yield the elasticity estimate. Note that the elasticity is not constant at different use levels.

From Table 4.15 it is evident that the elasticity estimates between the linear and multiplicative functional forms are statistically identical. Nonprice conservation program estimates are also similar. Estimates of conservation program effectiveness with the linear model are lower but of approximately the same overall effect. As with the multiplicative model, programming efforts are *most* effective during the spring and summer seasons. Water use reduction per program ranges between 0.6 and 2.0 percent depending on the season. Overall effectiveness of conservation

Table 4.15
Comparison of season specific model elasticity estimates:
linear and multiplicative forms

	Spring	**Summer**	**Fall**	**Winter**	**Seasonal Avg.**
Average Use/Acct. (1,000 gal/month)	11.00	18.00	12.00	8.00	12.25
Monthly bill $	21.50	33.00	23.00	17.00	23.63
With a 10% increase in marginal price $	23.15	35.80	24.80	18.20	25.49
Multiplicative Function					
Resulting Use/acct. (1,000 gal/month)	10.86	17.58	11.78	8.02	12.06
Elasticity	**-0.13**	**-0.23**	**-0.18**	**0.02**	**-0.15**
Linear Function					
Resulting Use/acct. (1,000 gal/month)	10.83	17.54	11.83	7.96	12.04
Elasticity	**-0.14**	**-0.24**	**-0.14**	**-0.04**	**-0.16**
Difference in Elasticity Estimates	0.01	0.01	0.04	0.06	0.01

programs averaged a 1.5 percent decrease as compared to a 2.2 percent decrease with the multiplicative model.

To summarize, the analysis results do not appear to be sensitive to the functional form of the demand model. Linear and multiplicative equations result in approximately the same estimates of price elasticity and nonprice conservation program effectiveness.

EFFECTIVENESS OF PRICE AND NONPRICE CONSERVATION PROGRAMS

As noted throughout this chapter, there is a trade-off between model accuracy and generality. The regional model is the most general, but the least accurate in predicting demand at an individual city level. The City/Season Specific model is the most accurate but the least general. The Season Specific model may be a reasonable compromise between generality and accuracy. We review and illustrate here the effectiveness of price and nonprice conservation programs within the Season Specific model context.

Figure 4.11 illustrates summer single-family residential water demand for various levels of marginal price based on the estimated coefficients of the Season Specific model. Water use and rate structures are similar to those outlined in the previous section on price responsiveness under the discussion of the Regional model. Though the summer season demand is the most price responsive, it is apparent from Figure 4.11 that only small decreases in demand may be expected with increases in price. Typical summer residential demand across the region is 18.30 thousand gallons per month at a marginal price of $1.50/unit. If a water utility were to increase the marginal price by $0.50 to $2.00 per thousand gallons, a non-trivial increase of 33 percent in water use rates, demand could be expected to decrease by less than seven percent to 17.10 thousand gallons per month, a reduction just slightly greater than one thousand gallons per month (-0.20 elasticity). Many utilities would find such a large increase in water rates politically difficult.

Nonprice conservation programs, on the other hand, appear to be effective in reducing demand without the high consumer cost and political consequences of a substantial increase in rates. An increase in the number of nonprice conservation programs, say from five to ten, is estimated to result in a reduction of demand of 11 percent as indicated by a shift in demand from D_1 to D_2 in Figure 4.12. In this scenario, residential summer use decreases from 17.09 to 14.80 thousand gallons per month, a reduction of more than two thousand gallons per month per household. Cost and thus cost effectiveness of these hypothetical programs is unknown but can be compared to the cost of similar reductions obtained through increases in water rates.

The effectiveness of price and nonprice programs is further illustrated Figures 4.13 through 4.15 by the experiences of Los Angeles, Denver and Albuquerque. From 1984 to 1994, (values taken from Table 4.10) Los Angeles effectively doubled its marginal water rates (from $1.28 to $2.56 measured in real terms; 1995 dollars) and implemented eight additional nonprice conservation programs. During this time, summer use per household decreased from 20.07 to 15.87 thousand gallons per month. Figure 4.13 indicates that approximately half of this decrease is due to a price increase (movement upward along the original demand curve to a higher price) and the other half is due to an increase in the number of nonprice conservation programs (shift of the demand curve to the left).

Between 1984 and 1994 Denver increased its marginal water rate by $0.37 (from $0.86 to $1.23 per thousand gallons, summer season) and imposed eight additional nonprice programs. Summer water use decreased from 26.05 to 22.31 thousand gallons per month during this period (Figure 4.14). The reduction in residential water use over this 11-year period can be attributed to both the price increase and the implementation of nonprice conservation programs. However, based on the results of the water demand models in this study, the majority of the reduction in water use is attributable to the nonprice conservation efforts made by Denver Water.

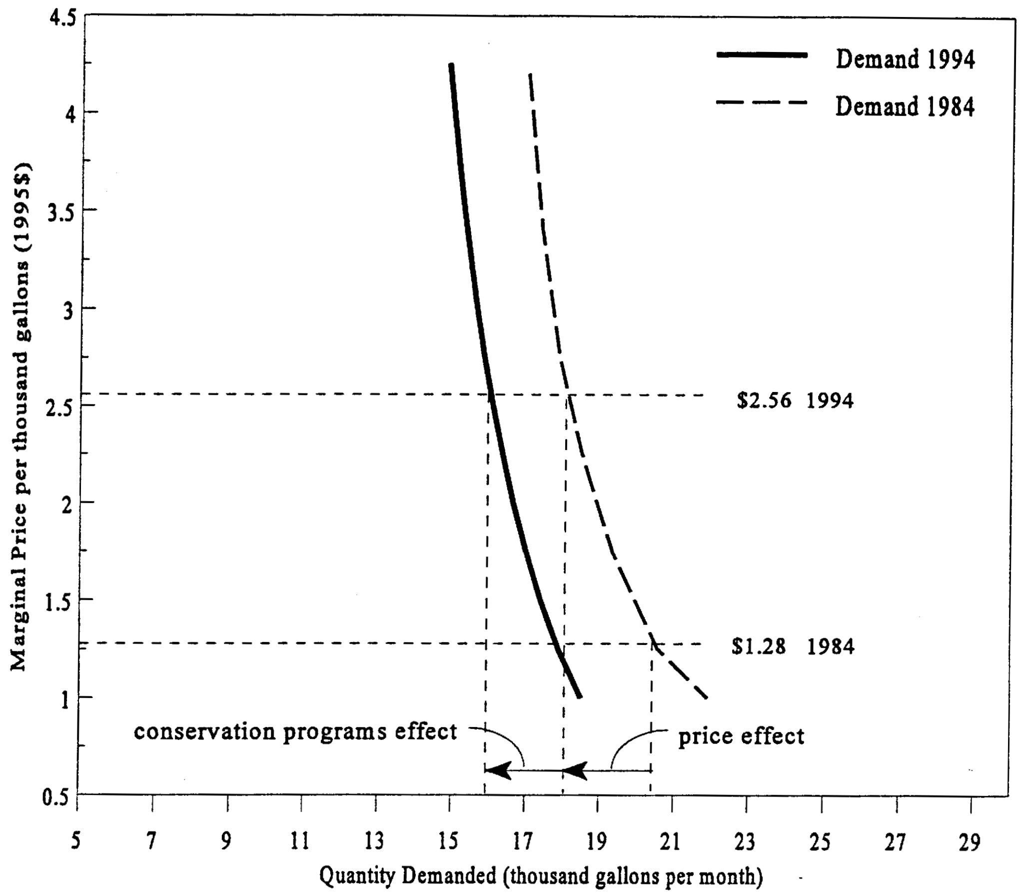


Figure 4.11 Regional household water demand: response to marginal price

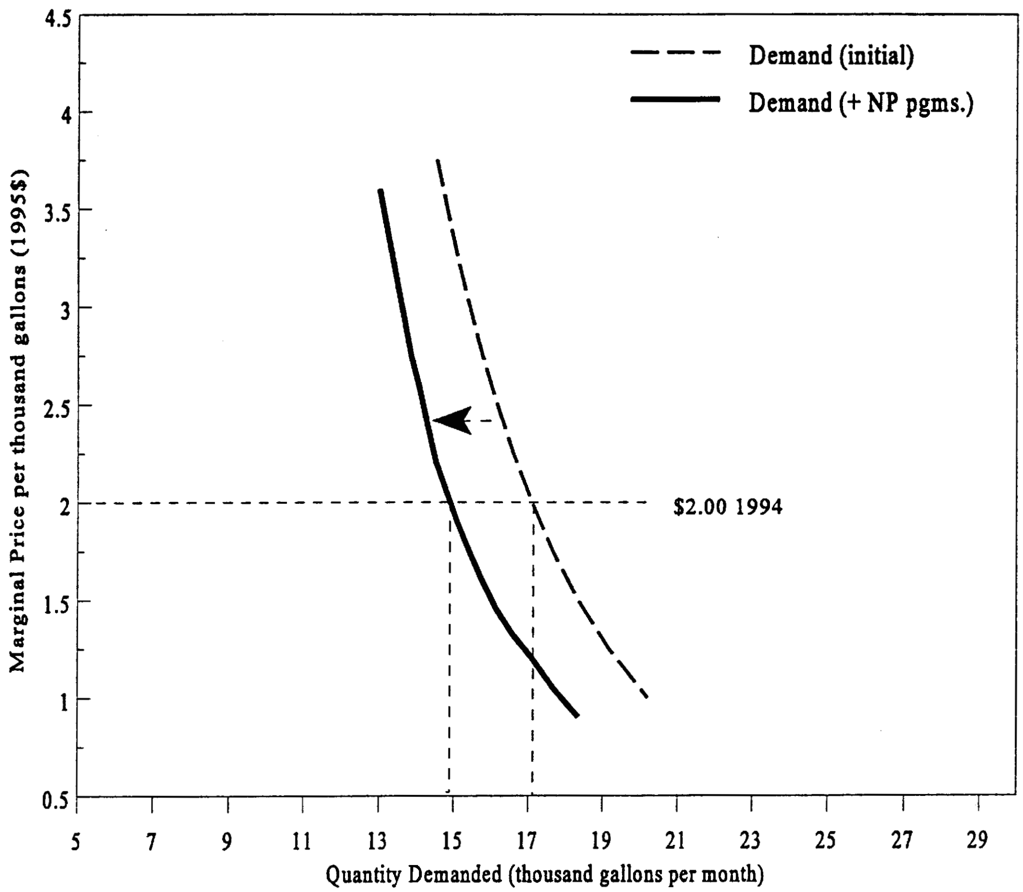


Figure 4.12 Regional household water demand: response to an increase in the number of nonprice conservation programs

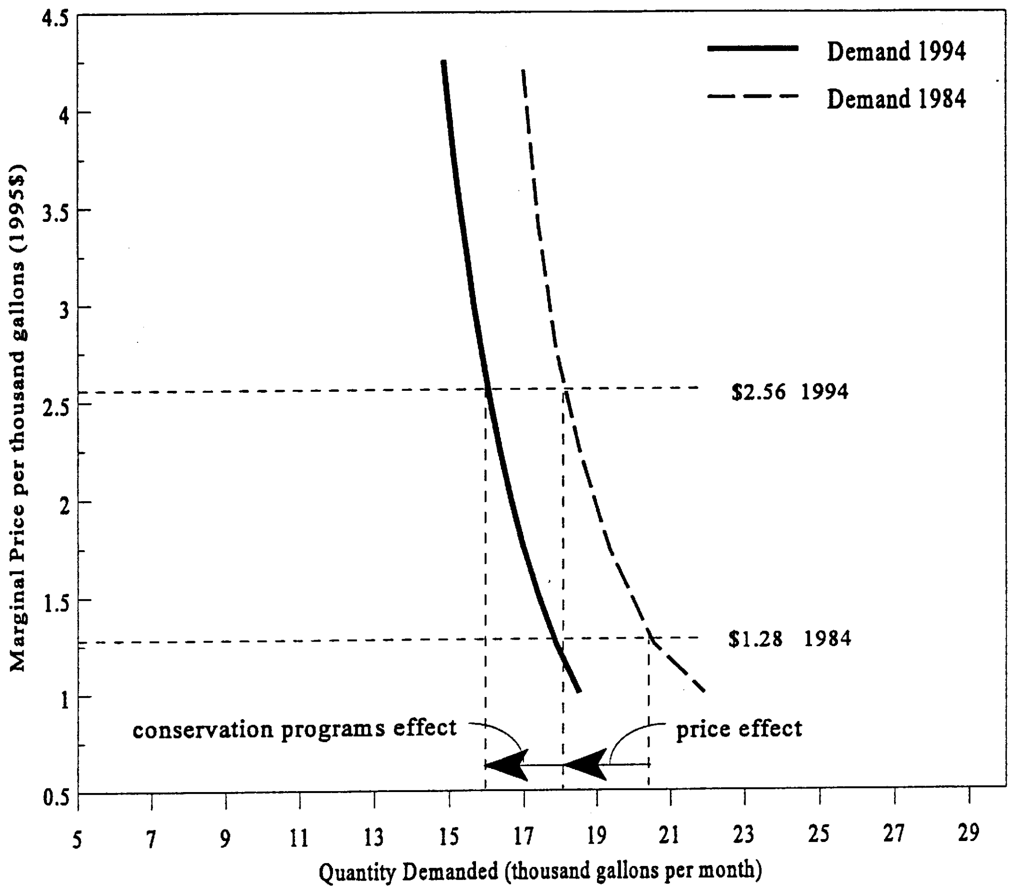


Figure 4.13 Los Angeles water demand 1984 and 1994: response to marginal price and nonprice conservation programs

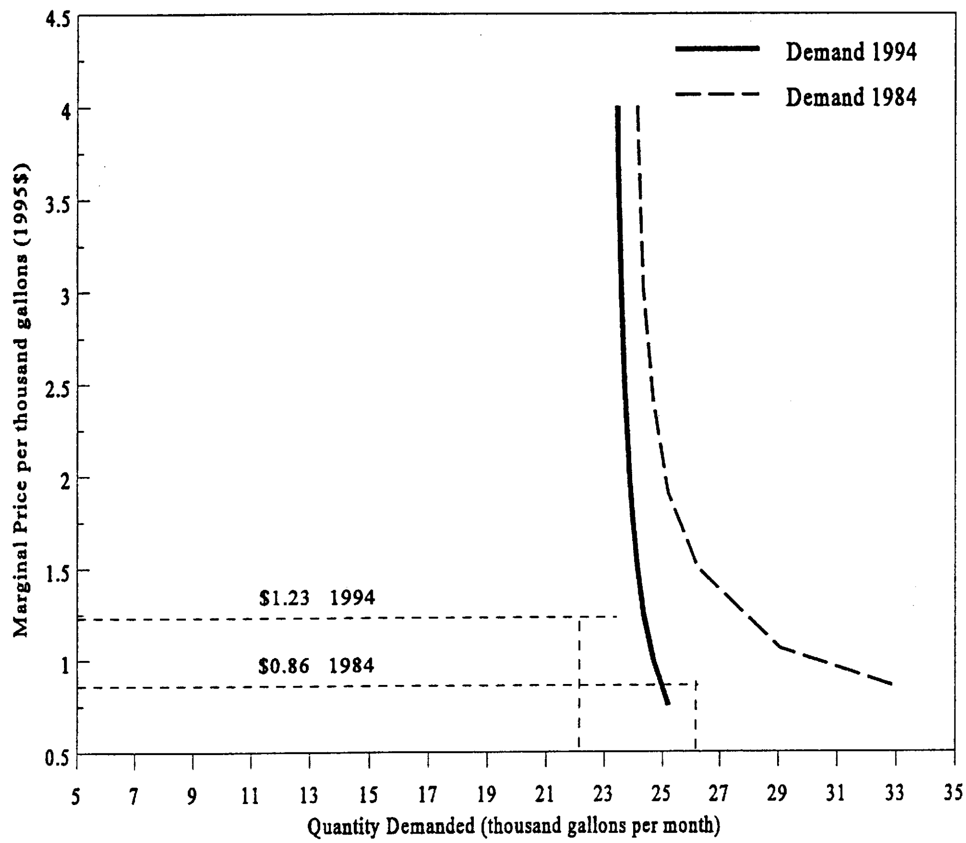


Figure 4.14 Denver water demand 1984 and 1994: response to marginal price and nonprice conservation programs

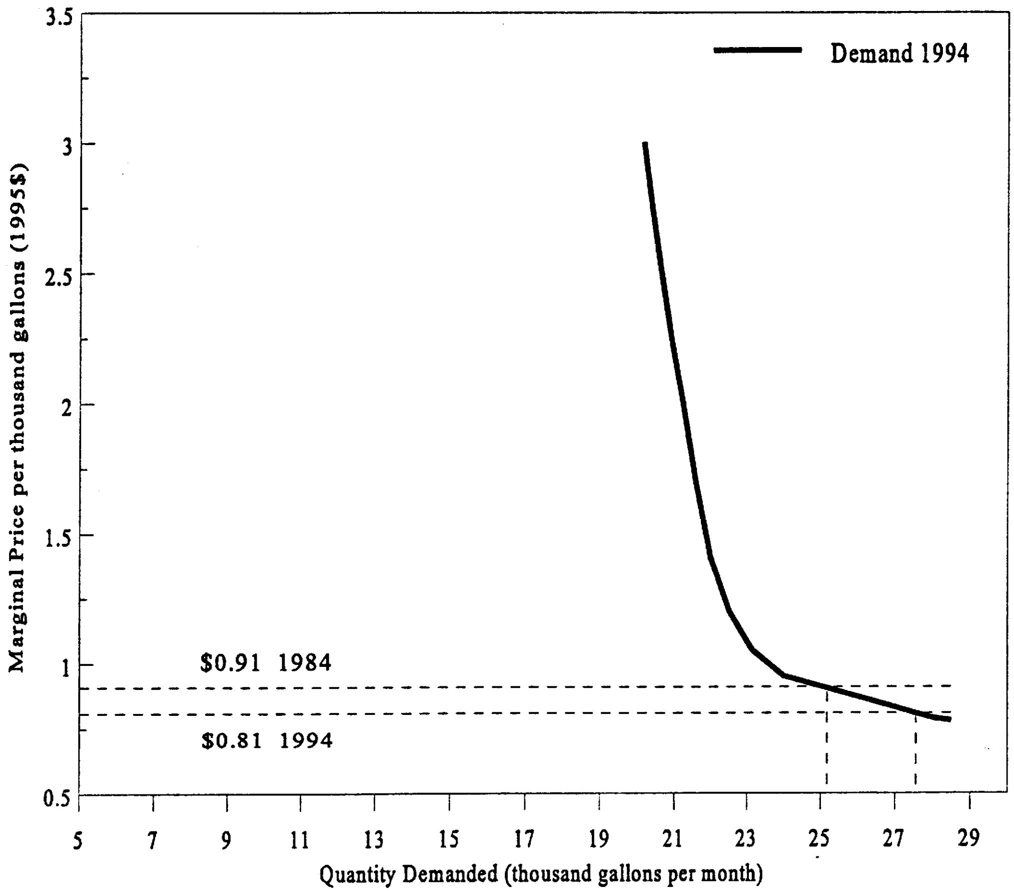


Figure 4.15 Albuquerque water demand 1984 and 1994: response to marginal price

Albuquerque's marginal water rate *decreased* in inflation adjusted 1995$ from $0.91 to $0.81 per thousand gallons between 1984 and 1994. Summer water use per residential household *increased* from 25.27 to 27.50. Figure 4.15 shows the estimated response to changes in marginal water price holding all other variables constant. Water demand model estimates indicate that this increase in water use in Albuquerque is due to a *decrease* in the real price of water and the absence of any nonprice conservation programs. It must be noted that Albuquerque's nonprice conservation programs only began in June of 1994.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF STATISTICAL MODELING RESULTS AND ANALYSIS

The overall objective of this research is to provide a clearer understanding and assessment of price and nonprice conservation program effects on single-family residential water demand. Questions addressed by this study include:

- How responsive are consumers to changes in the price of water?
- Are consumers responding to the average price, marginal price, or some combination of the two?
- How does demand change or respond to the implementation of nonprice conservation programs?
- Is it appropriate to model and apply study area results to other cities in the region?

Evaluation of changes in residential water use and conservation policies implicitly or explicitly requires a model of consumer choice, that is, a model of water demand. Three models of residential water demand were constructed and analyzed with the purpose of investigating the effectiveness of price and nonprice conservation programs. The first model (Regional) assumes that consumers in different cities respond similarly across the region and throughout the year to rate structures, price levels, nonprice conservation programs, climate, income and other factors. The second model (Season Specific) is designed to investigate seasonal variations in consumer response across the region to changes in rate structures, price levels, nonprice conservation programs, climate, income and other factors. The third model (City/Season Specific) is designed to investigate individual city and seasonal variations in consumer response to rate structures, price levels, nonprice conservation programs, climate, income and other factors.

Water Demand Models: Aggregation and Prediction Accuracy

Each of the three water demand models were successfully tested using maximum likelihood regression techniques with information from the pooled 10-year time series, cross-sectional database. All three models were able to predict water demand with a high degree of accuracy and almost all of the coefficient estimates were statistically significant and had the expected demand relationship (summarized in the next section). The models were also constructed to ascertain whether the modeling results could be extended beyond the seven cities in the database for a more general statement about residential water use in the southwestern United States. This was not the case. Though all three models predict residential demand with a high degree of accuracy, the City/Season Specific model was statistically a "better fit." However, this model lacks the generality and data variation to make statements about price and nonprice programs effectiveness beyond the scope of an individual city, that is Los Angeles's nonprice water conservation programs have been effective in that city, but one can not say that such programs will be effective elsewhere. Although the Regional and Season Specific models were statistically not as close of a fit, the parameter relationships (coefficient values) estimated by each of the three models were very similar. The Season Specific model provides a compromise in statistical accuracy and generality of results, incorporating the broader range of parameter values considered (all cities) on a detailed seasonal basis.

Conservation Program Effectiveness and Water Demand Relationships

What are the general findings of the statistical modeling? Water price has a significant and negative impact on water use, but water demand is very price inelastic, more so than has been suggested in other studies. The highest elasticity estimate was for summer use (approximatel -0.20). With this degree of responsiveness, water utilities could double their water rates and expect, at a maximum, only a 20 percent decrease in water use during the peak season. More likely, utilities should expect a water elasticity of -0.10 on an annual basis; a hefty 50 percent increase in rates will reduce use by 5 percent.

Statistical tests to determine whether consumers perceive and respond to marginal prices or average prices are inconclusive. Consumers appear to be responding to some combination of marginal and average prices. This makes it more difficult to design effective rate structures because it is not clear which price or prices consumers are responding to. This mixed consumer response is, in part, a result of the service charges prevalent in current rate structures. The use of fixed service charges with uniform or block rate structures results in declining average prices as consumption increases, even when marginal prices are rising. These results indicate that utilities interested in using price to encourage conservation should reexamine the incentives provided by their rate structures and, specifically, focus on reducing or even eliminating the fixed charge component or incorporate it into the rate structure in a different manner. Such changes would have to be considered in light of acceptable consumer cost allocations and revenue limitations and stability for the utility.

Nonprice conservation programs appear to be effective if the water utility achieves a critical mass of programs. For Los Angeles, San Diego and Denver, the number of nonprice programs have had the desired effect. For cities with fewer programs or relatively new experiences with conservation programs, the nonprice programs had no effect on demand. Conservation programs work independently of a drought environment, such as California's in the late 1980's and early 1990's and continue to work after the drought conditions have ceased. Conservation programs may be ultimately necessary simply to counteract an exogenous long-term increase in residential uses.

Climate effects residential use in predictable ways. Water use is strongly correlated with average monthly temperature and seasonal variation in temperature. Precipitation was consistently insignificant in all models. All cities in this analysis are semi-arid to arid in climate and thus the ratio of evapotranspiration to precipitation is much greater than one. Landscape watering is necessary if one wants to maintain typical residential lawns and trees. Random and infrequent rains do not change residential watering patterns to a significant degree.

Other variables, exogenous to a water utility, such as residential income and the size of the city also vary, but their influence is estimated to have a relative minor impact on residential use.

In summary, price and nonprice conservation programs are effective, but require a major commitment to implement. Consumers are very unresponsive to price increases under current rate structures, requiring large increases in price to achieve small reductions in demand. Nonprice conservation programs appear to be most effective when there are a substantial number of programs conducted over longer periods of time. Because the information regarding nonprice program is incomplete, we are not able to distinguish the effectiveness of individual types or specific programs nor the residual or lasting effects of nonprice programs. Small changes in water rates or implementation of haphazard conservation programs will most likely not produce discernable results.

ISSUES AND RECOMMENDATIONS

Price Elasticity Estimates and Water Demand Data

Water price elasticity (the responsiveness of consumers to changes in water rates) is estimated to be very low, even lower than what has been suggested in previous research. The Season Specific model (regional) water price elasticity is estimated to be -0.15 on an annual basis. For a 10 percent increase in water rates (marginal water price), use would be expected to decline only 1.5 percent. Consumer response is slightly more pronounced in the summer (elasticity = - 0.23) and less in the spring and fall (-0.13 and -0.18 respectively). Price elasticity is actually positive in the winter (0.02), but this may be due to other incentives. *These estimates indicate that, with current rate structures, consumers are very unresponsive to increases in price, and unless revenue enhancement is also an objective, increases in marginal prices alone are not effective in achieving reductions in residential water use.*

Based on a general but seemingly flawed assumption that consumers in different cities respond similarly to price changes, these and previous elasticity estimates may be under- or over-stated. Elasticity estimates can only reliably be derived for cities that have had significant real price changes. Because individual cities have generally not changed water prices significantly in real terms, it is more difficult to project elasticity of water use based on past experience, especially for individual cities that have experienced even less variation in prices.

Also, because of limited data availability, these and most price elasticity estimates of water demand are based on observations of average residential demand. Average water use information provides only a limited picture of consumer response. High use consumers (those at the upper margins of use and price which many conservation programs attempt to focus on) may be more responsive to increases in water price, but their response is statistically "lost" when measuring the average consumption across all consumers. *Billing period information about the number and change in number of consumers within each rate block is necessary to evaluate individual consumer response. In general, utilities do not record billing period data about the distribution of users within* *the block rate structure. This information is essential to more fully analyze the effects of increasing block rate price structures. Our recommendation is that utilities develop and maintain billing period records of the number of users and quantity of water consumed in each price block. This information would be relatively easy to obtain if gathered at the time of billing, but becomes almost impossible to recover from archived records.*

Conservation Pricing and Consumer Incentives

As noted above, consumers appear to be responding to some combination of marginal and average prices. Because of the service charge, most water utilities actually have declining average water rates even with an increasing block rate structure. *For conservation-oriented pricing, utilities should consider elimination or reduction of the service charge and recover the difference in revenue from an increase in the commodity (consumption) charge.* Given the price inelasticity of demand, utilities that decrease their service charge and implement higher commodity charges (marginal prices) are unlikely to experience insufficient annual revenue with the appropriate increase in price. Because consumer costs and payments are more closely related to the quantity of water consumed, this type of rate structure would increase variation in monthly revenues. For the same total annual revenue (a revenue neutral conservation incentive rate structure), the elimination of fixed charges and corresponding increase in consumption charges, would result in lower water bills for below average water users and higher water bills for above average users. *Small increases in water rates are not an effective method to reduce water use but will increase utility revenues.* Utilities that attempt to use minimal conservation oriented price structures and continue to apply monthly service charges not related to the quantity of water used for stability in their monthly revenues are unlikely to achieve much success in conservation through their price program.

Nonprice Conservation Program Documentation

One significant finding of this study is the overall lack of information available regarding the implementation of nonprice conservation programs and lack of detail and consistency of water use information necessary to evaluate changes in demand. Very little information about nonprice programs implemented in each city was available, and information that was available was not recorded in a consistent fashion. The lack of information directly impacted the evaluation methods that could be applied and the resolution of the analysis and results. *We recommend that utilities substantially increase support and efforts to document and maintain consistent records of conservation program activities, scope, specific periods of program implementation, measurable levels of effort and follow-up evaluations of program participation and responses.*

Recording details of specific nonprice conservation programs is crucial to evaluate consumer response to such efforts. Information should be recorded on a similar basis as water bills (i.e., monthly, bimonthly, etc.) to determine if program efforts influence customer use levels from period to period. Essential information includes, but by no means is limited to, descriptions explaining program focus, dates of implementation recorded on the same basis as water bills, and duration of programs. Also necessary is the level of effort throughout the program. For instance: how many customers received bill inserts; when were inserts distributed; how many calls were answered on the conservation hotline; how many school presentations were given and what was the attendance at each; how many retrofit devices were distributed and installed. Improved documentation will greatly facilitate future evaluations and is necessary to evaluate the effectiveness of individual conservation programs. Furthermore, with improved information, combinations of programs, proven to be successful in reducing water use levels in one city, could be applied to cities with similar characteristics in different regions in the United States.

APPENDIX A

City/season specific model results for Los Angeles

City/season specific model results for San Diego

City/season specific model results for Denver

City/season specific model results for Broomfield

City/season specific model results for Albuquerque

City/season specific model results for Santa Fe

City/season specific model results for Las Cruces

Table A.1
City/season specific model results for Los Angeles

Variable	Coefficient	Standard Error	Probability that the coefficient is not significant	Mean Log Value†	Mean Linear Value†
Constant	19.668	9.56	0.040	n/a	n/a
Acct	1.030	0.065	0.000	12.93	411,062
AP/MP Spring	-0.336	0.176	0.057	0.15	1.16
AP/MP Summer	-0.510	0.208	0.014	0.09	1.10
AP/MP Fall	-0.519	0.245	0.516	0.10	1.11
AP/MP Winter	-0.702	0.130	0.000	0.16	1.18
MP Spring	-0.079	0.115	0.495	0.49	1.68
MP Summer	-0.152	0.141	0.281	0.55	1.78
MP Fall	0.037	0.101	0.714	0.53	1.75
MP Winter	-0.163	0.086	0.059	0.47	1.65
Drought	-0.061	0.024	0.013	n/a	n/a
Time	-0.015	0.006	0.013	n/a	n/a
Income	1.075	0.387	0.005	10.49	35,900
Temp	0.762	0.110	0.000	4.20	66.70
Prec	-0.005	0.003	0.069	-1.83	1.07
Cons Spring	-0.052	0.010	0.000	n/a	9.56
Cons Summer	-0.032	0.012	0.010	n/a	8.55
Cons Fall	-0.044	0.009	0.000	n/a	9.64
Cons Winter	-0.034	0.008	0.000	n/a	9.60

Note: To convert the model to a per account basis subtract 1.0 from the *Acct* coefficient.

† Values calculated for the period covering January 1984 through April 1995.

Table A.2
City/season specific model results for San Diego

Variable	Coefficient	Standard Error	Probability that the coefficient is not significant	Mean Log Value†	Mean Linear Value†
Constant	18.37	9.56	0.043	n/a	n/a
Acct	1.030	0.065	0.000	12.12	183,513
AP/MP Spring	-1.069	0.477	0.025	0.13	1.14
AP/MP Summer	-1.380	0.776	0.075	0.07	1.07
AP/MP Fall	-0.391	0.608	0.000	0.10	1.10
AP/MP Winter	-1.586	0.357	0.000	0.17	1.19
MP Spring	-0.047	0.244	0.847	0.48	1.63
MP Summer	0.406	0.254	0.111	0.51	1.68
MP Fall	0.364	0.274	0.185	0.51	1.68
MP Winter	-0.247	0.245	0.313	0.49	1.64
Drought	-0.061	0.024	0.013	n/a	n/a
Time	-0.015	0.006	0.013	n/a	n/a
Income	1.075	0.387	0.005	10.57	39,350
Temp	0.968	0.211	0.000	4.16	64.31
Prec	-0.005	0.003	0.069	-1.23	0.91
Cons Spring	-0.036	0.101	0.000	n/a	8.88
Cons Summer	-0.047	0.104	0.000	n/a	8.95
Cons Fall	-0.021	0.009	0.033	n/a	9.09
Cons Winter	-0.014	0.009	0.119	n/a	9.14

Note: To convert the model to a per account basis subtract 1.0 from the *Acct* coefficient.

† Values calculated for the period covering January 1984 through April 1995.

Table A.3
City/season specific model results for Denver

Variable	Coefficient	Standard Error	Probability that the coefficient is not significant	Mean Log Value†	Mean Linear Value†
Constant	18.12	9.56	0.043	n/a	n/a
Acct	1.030	0.065	0.000	10.99	68,200
AP/MP Spring	0.228	0.217	0.293	0.33	1.40
AP/MP Summer	0.491	0.190	0.009	0.22	1.26
AP/MP Fall	0.201	0.185	0.278	0.23	1.27
AP/MP Winter	0.293	0.308	0.342	0.38	1.47
MP Spring	-0.213	0.269	0.429	-0.05	0.96
MP Summer	-0.256	0.273	0.350	-0.10	0.91
MP Fall	-0.196	0.203	0.335	-0.07	0.94
MP Winter	0.010	0.146	0.497	-0.03	0.98
Time	-0.015	0.006	0.013	n/a	n/a
Income	1.075	0.387	0.005	10.29	29,501
Temp	1.150	0.076	0.000	3.88	50.91
Prec	-0.005	0.003	0.069	-0.07	1.30
Cons Spring	-0.036	0.010	0.000	n/a	9.24
Cons Summer	-0.012	0.101	0.025	n/a	9.24
Cons Fall	-0.171	0.009	0.061	n/a	9.52
Cons Winter	-0.031	0.011	0.006	n/a	9.34

Note: To convert the model to a per account basis subtract 1.0 from the *Acct* coefficient.

† Values calculated for the period covering January 1984 through April 1995.

Table A.4
City/season specific model results for Broomfield

Variable	Coefficient	Standard Error	Probability that the coefficient is NOT significant	Mean Log Value†	Mean Linear Value†
Constant	19.339	9.560	0.043	n/a	n/a
Acct	1.030	0.065	0.000	8.80	6,650
AP/MP Spring	0.589	0.517	0.254	0.19	1.22
AP/MP Summer	-0.449	0.859	0.601	0.12	1.12
AP/MP Fall	-0.753	0.634	0.235	0.16	1.17
AP/MP Winter	-0.800	0.407	0.049	0.25	1.29
MP Spring	-1.295	0.566	0.022	0.70	2.02
MP Summer	-0.878	0.579	0.129	0.70	2.01
MP Fall	-1.041	0.579	0.073	0.69	1.99
MP Winter	-0.885	0.563	0.116	0.69	2.00
Time	-0.015	0.006	0.013	n/a	n/a
Income	1.075	0.387	0.005	10.31	29,955
Temp	0.983	0.082	0.000	3.89	50.84
Prec	-0.005	0.003	0.069	0.11	1.60
Cons Spring	n/a	n/a	n/a	n/a	n/a
Cons Summer	n/a	n/a	n/a	n/a	n/a
Cons Fall	n/a	n/a	n/a	n/a	n/a
Cons Winter	n/a	n/a	n/a	n/a	n/a

Note: To convert the model to a per account basis subtract 1.0 from the *Acct* coefficient.

† Values calculated for the period covering January 1984 through April 1995.

Table A.5
City/season specific model results for Albuquerque

Variable	Coefficient	Standard Error	Probability that the coefficient is NOT significant	Mean Log Value†	Mean Linear Value†
Constant	17.69	9.650	0.043	n/a	n/a
Acct	1.030	0.065	0.000	11.51	99,600
AP/MP Spring	0.194	0.456	0.670	0.04	1.62
AP/MP Summer	0.351	0.742	0.636	0.31	1.36
AP/MP Fall	0.129	0.528	0.807	0.41	1.51
AP/MP Winter	0.428	0.373	0.252	0.60	1.82
MP Spring	-0.644	0.452	0.155	-0.19	0.83
MP Summer	-1.269	0.522	0.015	-0.19	0.83
MP Fall	-1.450	0.550	0.007	-0.19	0.83
MP Winter	-0.317	0.437	0.470	-0.19	0.83
Time	-0.015	0.006	0.013	n/a	n/a
Income	1.075	0.387	0.005	n/a	n/a
Temp	1.138	0.096	0.000	4.00	56.84
Prec	-0.005	0.003	0.069	-0.62	0.88
Cons Spring	0.016	0.033	0.623	n/a	0.12
Cons Summer	-0.011	0.010	0.251	n/a	0.36
Cons Fall	-0.021	0.014	0.120	n/a	0.52
Cons Winter	-0.013	0.017	0.457	n/a	0.40

Note: To convert the model to a per account basis subtract 1.0 from the *Acct* coefficient.

† Values calculated for the period covering January 1984 through April 1995.

Table A.6
City/season specific model results for Santa Fe

Variable	Coefficient	Standard Error	Probability that the coefficient is NOT significant	Mean Log Value†	Mean Linear Value†
Constant	19.204	9.560	0.043	n/a	n/a
Acct	1.030	0.065	0.000	9.77	17,500
AP/MP Spring	-0.719	0.260	0.006	0.15	1.16
AP/MP Summer	0.293	1.274	0.818	0.07	1.07
AP/MP Fall	-0.269	0.432	0.532	0.10	1.11
AP/MP Winter	-0.597	0.206	0.004	0.20	1.23
MP Spring	-0.131	0.069	0.059	1.34	3.89
MP Summer	-0.062	0.083	0.457	1.39	4.05
MP Fall	-0.099	0.063	0.116	1.37	4.00
MP Winter	-0.018	0.067	0.789	1.30	3.74
Time	-0.015	0.006	0.013	n/a	n/a
Income	1.075	0.387	0.005	10.46	34,950
Temp	0.624	0.072	0.000	3.88	50.57
Prec	-0.005	0.003	0.069	-0.13	1.34
Cons Spring	0.023	0.014	0.108	n/a	1.59
Cons Summer	0.022	0.013	0.098	n/a	1.55
Cons Fall	0.029	0.013	0.028	n/a	1.66
Cons Winter	0.024	0.013	0.059	n/a	1.66

Note: To convert the model to a per account basis subtract 1.0 from the *Acct* coefficient.

† Values calculated for the period covering January 1984 through April 1995.

Table A.7
City/season specific model results for Las Cruces

Variable	Coefficient	Standard Error	Probability that the coefficient is NOT significant	Mean Log Value†	Mean Linear Value†
Constant	17.869	9.560	0.043	n/a	n/a
Acct	1.030	0.065	0.000	9.61	14,912
AP/MP Spring	0.156	0.356	0.660	0.11	1.13
AP/MP Summer	1.819	0.597	0.002	0.05	1.05
AP/MP Fall	-0.413	0.419	0.326	0.07	1.07
AP/MP Winter	0.154	0.225	0.493	0.56	1.81
MP Spring	0.500	0.382	0.191	-0.01	1.00
MP Summer	0.722	0.484	0.135	0.03	1.03
MP Fall	-0.302	0.486	0.533	0.04	1.04
MP Winter	0.550	0.251	0.029	-0.33	0.75
Time	-0.015	0.006	0.013	n/a	n/a
Income	1.075	0.387	0.005	10.23	27,704
Temp	1.210	0.091	0.000	4.10	61.98
Prec	-0.005	0.003	0.069	-0.83	0.92
Cons Spring	n/a	n/a	n/a	n/a	n/a
Cons Summer	n/a	n/a	n/a	n/a	n/a
Cons Fall	n/a	n/a	n/a	n/a	n/a
Cons Winter	n/a	n/a	n/a	n/a	n/a

Note: To convert the model to a per account basis subtract 1.0 from the *Acct* coefficient.

† Values calculated for the period covering January 1984 through April 1995.

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