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Integration of Supply and Demand for Water In Central Illinois Urban Areas

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ABSTRACT

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Water demand functions were estimated using two sets of data for Central Illinois -- community-wide data and household data. The community-wide data consist of total residential consumption for each of four pre-selected medium-sized cities in Central Illinois. The household data consist of residents from five cities who responded to a mail survey. This study investigates comparability of parameter estimates from the two approaches. If the parameter estimates are comparable, it would suggest water demand estimates need not require costly and time-consuming household surveys. Estimates of price elasticity are negative and less than unitary based on the two data sets used. The estimated price elasticity based on community-wide data is -.037, while using household data estimated price elasticities are in the range from -.14 to -.16. Estimated income elasticities for central Illinois households are positive. The estimated income elasticity based on community-wide data is 1.57 while the estimated income elasticity based on household data ranges from .0759 to .316. In comparing results of the general demand model based on the two sets of data, there is wide disparity in the values of the estimated price and income elasticities. The reasons for these differences are not immediately apparent and warrant further investigation.

Key words: water demand, price elasticity, income elasticity

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CHAPTER 1

INTRODUCTION

A. Background and Nature of the Problem

Several central Illinois communities, including Decatur and Bloomington, in recent years have experienced an imbalance between demand and supply of water. The increase in urban populations and the occurrence of recent climatic phenomena such as droughts have led to an increase in demand for water. Past responses to such conditions, have relied on attempts at supply augmentation and demand regulation by fiat, since most municipal utilities have assumed that aggregate water demand is a function of population and that quantity of water demand to be unrelated to the water's price (Martin, Ingram, Laney and Griffin, 1984).

However, economic theory suggests that the quantity of water demanded is affected by factors such as water prices, consumer incomes, climatic factors, consumer tastes, and preferences. With the aid of economic theory, estimation of water demand through demand models can be conceptualized.

In the urban communities of central Illinois, there is currently little knowledge of the determinants of demand for urban water. Knowledge of these determinants would be particularly useful to water system managers and planners. Not only would it give them a better understanding of the economics of urban water demand but it would provide them with an additional tool for optimum water system planning and management.

B. Objectives

The following are the objectives of this study:

1. Estimate water demand functions for central Illinois consumers.
2. Improve on the existing information base on water demand in urban communities in central Illinois.
3. Compare water demand estimates from two data sets: aggregate and household data.

C. Scope and Limitation of the Study

The study is based on two data sets: (1) aggregate residential water consumption data from 1981-1989 for four central Illinois communities provided by their respective water utilities; and (2) household residential water consumption for 1990 obtained through a mail survey for five central Illinois communities. Due to the limited scope of this study, the results may not be used as an encompassing or a definitive basis for describing the demand for water in central Illinois. However, the depth of analysis hopefully will provide useful insights for further research.

D. Outline of the Thesis

In Chapter 2 a review of related research is presented on water demand. The model of residential water demand is presented in Chapter 3 along with a description of the data to quantify the models. In Chapter 4 the empirical results are presented. Finally, Chapter 5 contains a brief summary of the major findings of the study.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

The 1967 article by Howe and Linaweaver entitled "The Impact of Price on Residential Water Demand and Its Relation to System Design", is considered the classic study of residential water demand. The paper developed formal econometric estimates of urban water relationships of several major western cities and demonstrated how these estimates could be useful in system design and price policy.

Subsequently, there have emerged three approaches to analyzing water demand. These are: (a) formal econometric analysis focusing on theoretical consistency and statistical precision; (b) complex simulation models aimed at forecasting municipal and industrial water use; and (c) synthesis and transfer of existing econometric knowledge, theory and important data for actual policy decisions in specific circumstances.

A. Econometric Analysis

In this approach, the emphasis is on the development of econometric methods in order to estimate for a given site the precise relationship between water demanded and price. The main insights are summarized in estimates of price elasticities.

1. Pricing Structure

Water supply prices are often structured in block rates, either ascending or descending. The fact that prices are discontinuous, and further that they may decline as supply increases, presents difficult econometric problems in estimating accurately the demand for water. Taylor (1975) in his survey of electrical demand studies pointed out that under multi-part tariff structures, the price variable should include both marginal price associated with the block where consumption occurs and an average price. Nordin (1976) extended Taylor's theoretical price specification under a declining block rate structure by suggesting that a utility maximizing consumer with perfect information would react not only to marginal price but also to changes in consumer surplus resulting from movement from one block to the next block. According to Nordin consumers interpret this rate premium as a loss (gain) in income and that these intramarginal price effects should be included in the demand equation. Nordin modified Taylor's theoretical price specification by including a marginal price and a difference variable to capture the effects of the intramarginal price rate or rate premium.

The difference variable, D, is defined as the actual total expenditure of the consumer less the expenditure if all units had been purchased at the marginal price. Nordin concluded that *a priori* the coefficient of D should be equal in magnitude but opposite in sign to that of income in a linear demand function.

Nordin's theoretical model was first used in empirical research on residential water demand by Billings and Agthe (1980) and Howe (1982) with limited success. Billings and Agthe (1980) estimated a residential water demand function for Tucson, Arizona. Howe (1982) reestimated the residential water demand from the data set used in the 1967 study of Howe and Linaweaver. In both studies the derivative of the demand function with respect to the difference variable (D) were opposite in sign but not equal in magnitude relative to income. The latter result failed to meet *a priori* expectations.

Martin and Griffin agreed with Nordin's theoretical specification of marginal price and the difference variable (D) as the price variables determining quantities demanded under multi-part tariff structure. However, Martin and Griffin concluded that the demand function will not be estimated correctly in an ordinary regression analysis where marginal price and the difference variable are the explanatory variables. They claimed that the relationship between the price and quantity as indicated by the regression was actually a relationship resulting from the combined effect of the rate schedule and the demand function. To derive the actual demand function, Martin and Griffin suggested an iterative procedure. The procedure involved performing an initial regression using prices in the use blocks intersected by the means of observed consumption to derive the first approximation of the demand curve. A second regression is performed utilizing prices in the use blocks intersected by the initial approximization of the demand curve. This procedure is continued until the estimated values of the intercept and the coefficients stabilized.

Foster and Beattie (1981b) questioned the theoretical validity of the marginal price-expenditure difference demand model and perfect knowledge assumption by analyzing cross section data for water consumption in 218 US cities. Foster and Beattie (1981b) argued that proper specification in consumer demand estimation depended on consumers' perceptions of price rather than what theory predicted was the measure of price. Foster and Beattie further suggested that whether consumers react to marginal or average price was basically an empirical question. Polzin (1984) drew similar conclusions in his study of residential gas demand in Great Falls, Montana where he claimed that the general lack of knowledge by consumers of the concepts of marginal prices and block rate structures resulted in the consumers responding to average as opposed to marginal prices. In this connection, Opaluch (1982) developed a model to test whether consumers respond to marginal price or average price under a multi-part tariff structure. Chicoine and Ramamurthy (1986) used the Opaluch model to estimate residential water demand functions for consumers facing declining block rate structures living in rural central Illinois communities. Their results suggest that consumers react to neither marginal nor average price.

Deller, Chicoine and Ramamurthy (1986) and Agthe, Billings, Dobra and Raffiee (1986) addressed the problem of simultaneity between price and quantity demanded. The problem arises because the price of water both determines and is determined by consumption under a block pricing scheme. These studies addressed the issue by using the instrumental variables method. The empirical results of

Deller *et al.* suggested that ordinary least squares (OLS) and three stage least squares under decreasing block rate structure yield similar estimates. This finding provides support for the use of simpler single equation models. In the study by Agthe *et al.*, a Hausman specification test was used to detect the presence of bias due to simultaneous determination of price and quantity. The presence of bias was confirmed. An alternative simultaneous equation model was used to reestimate residential water demand for Tucson, Arizona. The empirical results are consistent with *a priori* expectations and unbiased.

Residential water demand analysis using microdata (observations on individual customers) have been relatively few. Danielson (1979) analyzed a cross-section and monthly time series of data from a sample of 261 households in Raleigh, North Carolina between May 1969 and December 1974; Hanke and de Mare (1982) analyzed a cross-section and monthly time series of data from a sample of 69 single-family homes in Malmo, Sweden between 1971 and 1978; Deller, Chicoine and Ramamurthy (1986) and Deller, Chicoine and Ramamurthy (1986) analyzed cross-section data in 1982 from a sample of 100 households in 59 districts in rural Illinois and Nieswiadomy and Molina (1988) and Nieswiadomy and Molina (1989) analyzed cross-section and monthly time series of data from a sample of 104 households in Denton, Texas for the summer months of 1981 to 1985. According to Schefter and David (1985) studies using micro data are more reliable than utilizing aggregate data since the latter may result in biased estimates of coefficients of the demand function.

Griffin and Chang (1990) employed various pretest analyses to recommend or eliminate certain specifications for water demand. These specifications included: the average price versus marginal price specification for pooled monthly data; the inclusion of sewer rates in water demand models; and the study of seasonal demand rather than annual demand. Their study employed 3 years of monthly aggregate water consumption data for 30 selected Texas communities. Empirical results were as follows: consumers respond to average price rather than to marginal price; an appropriately specified hypothesis indicated that community water demand models should include sewer rates; and summer price and winter price elasticities exhibited seasonal variability where summer price elasticities are approximately 50 percent more elastic than winter elasticities.

In conclusion, the results of empirical studies on the relation of the residential water demand to the pricing structure has been relatively mixed. Most recent work on water demand has included multiple price variables to capture substitution and income effects of rate changes under multi-part tariff structures. According to Griffin and Chang (1990) neither AP nor MP formulations are capable of this in isolation.

2. Empirical Estimates of Price Elasticities

Al-Qunaibet and Johnston (1985) present a table of 19 studies classified by types of data (cross-section, time series or pooled), region studied and by functional model comparing price elasticities (as well as income elasticities) and goodness of fit (R^2's) of the models. Table 1 reproduces the summary of Al-Qunaibet and Johnston and adds results from more recent studies by Billings and Agthe (1980), Billings (1982), Chicoine, Grossman and Quinn (1984), Chicoine, Deller and Ramamurthy (1986), Nieswiadomy and Molina (1988, 1989) and Griffin and Chang (1990). With some exceptions, the cumulative evidence suggests price elasticities that generally fall in the range from -.15 to -.73. Thus quantities change less than in proportion to prices. The estimates of income elasticities have generally fallen within the range of 0.11 to 0.70. In this range, quantity increases less than in proportion to income.

B. Simulation Analysis

This approach emphasizes forecasts of municipal and industrial use. It is exemplified by the work of Dziegielewski, Boland and Baumann (1981) and by Dziegielewski and Boland (1989). In the latter study, Dzigielewski and Boland applied the IWR-MAIN (Institute for Water Resources-Municipal and Industrial Needs) computerized forecasting model to Anaheim, California.

The simulation models are not entirely independent of the econometric models because they require estimates of price response that are derived econometrically. The residential water use equations chosen and used by Dzielewski and Boland came from the studies conducted by Howe and Linaweaver (1967) and Howe (1982).

TABLE 1 Summary of Selected Municipal Water Demand Studies

Investigator	Type of Data and Region Studied	Model	Price Elasticity	Income Elasticity	R^2
Fourt (1958)	CS (United States)	double log	-0.387	0.277	0.303
Gottlieb (1963)	CS (Kansas)	double log	-0.656 to -1.234	0.278	0.83 to 0.85
Howe and Linaweaver (1967)	CS (United States)	linear(domestic)	-0.231	0.319	0.717
		double log			
		(sprinkling)	-1.12	0.662	0.729
		(total)	-0.405	0.474	0.743
Wong (1972)	CS (Illinois)	double log	-0.26 to -0.82	0.48 to 1.03	0.30 to 0.5
Grima (1972)	CS (Ontario, Canada)	double log			
		(summer)	-1.07	0.51	0.55
		(winter)	-0.75	0.48	0.49
		(total)	-0.93	0.65	0.56
Andrews and Gibbs* (1976)	CS (Miami, Florida)	exponential			
		(AP model)	-0.62	0.80	0.46
		(MP model)	-0.51	0.51	0.60
Batchelor (1975)	CS (Malvern, United Kingdom)	linear	-0.23 to -0.28	0.38 to 0.93	...
Clark and Asce (1976)	CS (United States)	linear	-0.63	...	0.45
Morgan and Smolen (1976)	CS (Southern California)	linear	-0.44	0.33	0.68
Foster and Beattie (1979)*	CS (United States)	price exponential			
		(aggregate)	-0.53	0.18	0.58
		(regional)	-0.33 to -0.68	0.37	0.71

Continuation of Table 1

Headley (1963)	TS (Bay Area, California)	linear	...	0.0014 to 0.40	...
Wong (1972)	TS (Chicago and suburbs, Illinois)	double log (Chicago)	-0.018	0.195	0.90
		(suburbs)	-0.283	0.258	0.76
Seawell and Roueche (1974)	TS (Victoria, British Columbia, Canada)	linear (annual)	-0.457	0.268	0.79
		double log (annual)	-0.395	0.191	0.80
Katzman (1977)	TS (Penang Island, Malaysia)	linear	-0.10 to -0.20	...	0.03 to 0.99
Danielson (1979)	pooled (Raleigh, N. Carolina)	double log (total)	-0.272	0.334	...
		(summer)	-1.38	0.363	
		(winter)	-0.305	0.352	...
Billings and Agthe (1980)**	TS (Tucson, Arizona)	linear	e_1 =-0.49 e_2 =-0.14	...	0.82
		double log	e_1 =-0.267 e_2 =-0.123	1.68	0.83
Billings (1982)**	TS (Tucson, Arizona)	linear	e_1 =-0.66 e_2 =-0.08	...	0.82
		double log	e_1 =-0.56 e_2 =-0.09	2.14	0.81
Hanke and deMare (1982)	pooled (Malmo, Sweden)	linear	-0.15	0.11	0.26
Chicoine, Grossman and Quinn (1984)	CS (rural Illinois)	exponential	-0.289		0.56
Chicoine, Deller Ramamurthy (1986)	CS (rural Illinois)	linear	e_1 =-0.22 e_2 = ---	0.01	0.69

Continuation of Table 1

		2SLS			
			e_1 =-0.42 e_2 =-0.27	0.08	----
		3SLS			
			e_1 =-0.42 e_2 =-0.29	0.14	----
Nieswiadomy and Molina (1988)	CS TS (Denton, Texas)	linear	---	0.305	0.54
		IV	---	0.20	0.12
		2SLS	---	0.13	0.12
Nieswiadomy and Molina (1989)	decreasing block	linear	-0.68	0.07	0.46
		IV	-0.09	0.20	0.34
		2SLS	-0.36	0.15	0.31
	increasing block	linear	-3.50	0.10	0.38
		IV	-0.86	0.14	0.26
		2SLS	-0.55	0.14	0.11
Griffin and Chang (1990)	CS TS pooled (Texas) model a	linear (winter)	-0.19	0.48	0.49
		(summer)	-0.37	0.30	0.49
	model b	(winter)	-0.16	0.48	0.49
		(summer)	-0.38	0.30	0.49

R^2 is the coefficient of multiple correlation. CS is cross-section study. TS is time series study, and pooled is pooled cross section-time series study.

* AP model is the model with the average price as price variable, and MP model is the model with marginal price as price variable.

** the e_1 and e_2 are marginal price and difference demand elasticities, respectively.

Source: Al-Qunaibet and Johnston 1985, Table 1, p.434 with updates after 1985.

C. Non-Traditional Analysis

The third approach eschews detailed quantitative analysis of specific circumstances eschews detailed quantitative analysis of specific circumstances and relies instead on syntheses of existing econometric knowledge, theory and important data. This general approach to policy knowledge was advocated by King (1979) and has been applied to urban water demand by Martin and Thomas (1986) and Martin and Kulakowski (1991). Martin and Thomas (1986) argued that precise estimates of demand elasticities may not be necessary for policy purposes in specific cities. Rather, approximate elasticity estimates based on cross-sectional demand comparisons in similar areas could be used with little loss of precision. In a follow-up study, Martin and Kulakowski (1989) utilized informal time-series analysis for Tucson, Arizona to gain insights on the effectiveness of changes in water price policy. If the stated objective of any city was water conservation, in the experience of Tuscon water education (preachments) alone would be an ineffective conservation management tool as observed by Martin and Kulakowski. To achieve significant long-term water reduction, Martin and Kulakowski argued that significant real water price increases would be required. According to Martin and Kulakowski for Tuscon to maintain constant rather than increasing water use, nominal water price would have to be raised by the rate of inflation plus approximately the rate of change in real per capita income.

Generally, Martin and colleagues make the argument that much is already known about price and income elasticities for water, and that what is needed for policy purposes is more descriptive examinations of urban areas in order to place those areas within a broad theoretical and empirical perspective. Policy makers are better served when provided with general knowledge about income and price elasticities than "econometric point estimates where the implied 'all other factors remaining constant' detract from the policy makers more applied points of view" (Martin and Thomas, 1986). Complex econometric studies can play a supplementary role by "suggesting" the likely magnitudes and directions of price and income elasticities, but very simple statistical analysis is enough to confirm that the price response of residents of the city or area in question is well within the range defined by previous sophisticated analyses.

The primary objective of this study is to estimate a functional relationship between the quantity of water demanded and variables affecting demand such as water prices, consumer incomes, climatic factors, consumer tastes and preferences. The demand relationships will be estimated using appropriate econometric techniques as suggested in the review of literature. A second objective is to improve the information base on water demand in humid areas. According the review of literature, there is little known about urban water demand in humid areas and, in particular, in central Illinois communities. Finally, using econometric analysis and non-traditional analysis, another objective is to compare the demand estimates from the two sets of data: aggregate and household data.

CHAPTER 3

METHODS

The principal objective of this study is to estimate urban residential water demand in Central Illinois communities using econometric techniques.

Two types of data sets are employed. The first data set contains pooled time-series cross-section data on aggregate residential water consumption. These data were obtained from 26 water utilities serving communities in central Illinois. The second data set contains pooled time-series cross section data on household water consumption. These data were obtained through a mail survey of a sample of residents in Central Illinois communities served by cooperating water utilities. A major thrust of the analysis will be to compare the demand estimates from the two different sets of data with the aim of determining how well aggregate data represent choices that are actually made at the household level.

A. General Water Demand Models

The general demand model to be used to estimate residential water demand adapted from Griffin and Chang (1990):

$$Q = b_0 + b_1AP + b_2PO + b_3Y + b_4C + u \qquad (1)$$

where:

Q is per household residential water consumption measured in 100 cubic feet (ccf) per month;

AP is average price of water paid by the household;

MP is marginal price of water paid by the household;

PO is MP-AP;

Y is the annual per capita income , measured in thousands of dollars;

C is a climatic variable to be defined; and

u is an error term.

The same model will be applied twice, once to the aggregate and once to the household data. Hypotheses tests suggested by Griffin and Chang (1990) can be used to test whether average price (AP) or marginal price (MP) or both give better specification of the water price variable. The Nordin difference variable (D) that captures the income effect resulting from changes in the inframarginal rates is excluded from the model because, according to Griffin and Chang (1990), the D and PO variable are likely to be highly correlated.

Following Griffin and Chang (1990), the calculated monthly climatic variable (C) is defined as the number of days without significant rainfall ($\geq$ 0.25 inches) times the month's average temperature. According to Griffin and Chang (1990), C captures: (1) summer lawn watering behavior, which will increase with higher temperature and more dry days; (2) winter behavior where low temperatures and more dry days occur; and (3) the effects of different numbers of days in the month.

Estimated price coefficients from the two regressions will be used to calculate estimated price elasticities of demand from the two types of data sets. Seasonal price elasticities will be calculated by reestimating equation (1) by adding price-climate cross products. Summer will be defined for the months of April to October while winter will be defined for the months of November to March. Summer price elasticities of demand are theorized to be more elastic than winter price elasticities.

A pooling test will be conducted to test if pooling is appropriate for the data. Chicoine, Deller and Ramamurthy (1986) observed that data from different water systems causes problems in modeling demand. A test procedure for analyzing cross-sectional data, adopted from Griffin and Chang (1990) and using an F-test will be employed. The F-test statistic is as follows:

$$F = (S_2 - S_1)(T-KN)/((KN-K)S_1)$$

where

S_1 is the sum of the residual sum of squares for K individual regressions;

S_2 is the residual sum of squares for a single regression using all the pooled data;

T is the number of pooled observations;

K is the number of cross sections; and

N is the number of parameters to be estimated.

The pooling test described above will be used on the two types of data employed in this study.

B. Expanded Household Demand Model

The general demand model in equation (1) will be augmented with several socio-economic variables for more detailed analysis of the household data set. The augmented model is:

$$Q = b_0 + b_1AP + b_2PO + b_3Y + b_4C + b_5N + b_6T + b_7S + u \qquad (2)$$

where:

N represents the number of persons in the household;

T represents the number of flush toilets in the house; and

S represents the number of showers or tubs in the house.

The added socio-economic variables were suggested by Chicoine, Grossman and Quinn (1984) in their study of households located in rural water districts. The number of flush toilets and showers provide a measure of household water-using technology. In a study by Hanke and de Mare (1982), their findings suggest that the number of bathrooms contribute to a larger water use, other things equal.

Price elasticities of demand computed from equation (2) will be compared to the earlier results of price elasticities calculated from the microdata, to determine whether the augmented model suggests different price and income elasticities.

A nested hypotheses tests for the augmented general water demand model will be conducted by using the Wald Chi-Square statistic. The first nested hypothesis tested is:

H_0: b_H, b_T, $b_S = 0$

The second nested hypothesis tested is:

H_0: b_T, $b_S = 0$

Testing the two nested hypotheses will determine whether the additional variables add explanatory power and should be included in the augmented general water demand model.

C. DATA

1. Aggregate Cross-sectional Data

In 1990, water utilities in 26 central Illinois urban communities were sent questionnaires on average monthly household water consumption, water prices and other relevant information for 1981-1989. Supplementary data were also obtained from the Water Inventory Program of the Illinois State Water Survey which included precipitation and temperature data.

A pooled cross-section time series data set on monthly average water consumption by community for years ranging from 1981 to 1989 was constructed for four communities. These communities include: Bloomington, Danville, Normal and Rantoul. It was only in these four communities that a monthly time-series data average water consumption were available for the entire nine year period.

The completed data set contains 108 months of data for each of the four communities. Water rate structures are presented in the appendix. In communities with block rate price structures, the first block price water rate was selected for use in the estimation because mean water consumption fell within the first block. Information concerning the range, mean, and standard deviation of individual variables is also presented in the appendix.

2. Household Data

In the questionnaires that were sent to the central Illinois water utilities, the water utility was asked if it would permit a survey to be administered to a sample of its respective customers. Based upon the response of the central Illinois water utilities, the communities of Champaign-Urbana, Danville, Rantoul, Normal and Bloomington were chosen as the study sites.

The goal was to obtain 350 complete and usable questionnaires for each community. Each of the central Illinois water utilities of the selected study sites provided the researcher a mailing list of 350 randomly selected households in each of their respective communities. Questionnaires were sent out to these households on July 28, 1991. As an incentive to complete the questionnaire, each potential respondent was given the opportunity to participate in a lottery, where two households in each respective community would be selected to receive a cash prize of $50 each.

The completed data set contains 1989-1990 water consumption data and augmented by socio-economic data for each household in the selected five communities. A copy of the sample household questionnaire and information concerning the results of the administration of the household water survey are presented in the appendix.

It should be also noted that in communities with block rate price structures, the first block price water rate was selected because it was observed that household water consumption fell within the first block.

CHAPTER 4

RESULTS

A. General Demand Model with Aggregate Data for a Pooled Sample

The first regression was based on the pooled cross-section and time-series data of the aggregate average monthly residential consumption. The general demand model used to estimate residential water demand is as follows:

$$Q = b_0 + b_1AP + b_2PO + b_3Y + b_4C + u$$

In communities with block rate price structures, the first block price water rate was selected because it was observed in all cases that average household water consumption fell within the first block. The initial results were statistically significant and the estimated price, income and climate coefficients had the expected signs. However, the initial results indicated significant autocorrelation and heteroskedasticity. The problem of autocorrelation frequently occurs in economic time series data since often there is a correlation in the errors corresponding to successive time periods. Heteroskedasticity refers to the violation of the assumption of errors having a constant variance. It is often prevalent in cross-section data. After correcting for autocorrelation and heteroskedasticity, the results of the water demand model are as follows:

$$Q = -7.0236 - 0.3101\,P + 0.014395\,Y + 0.0009463\,C$$

$$(1.276) \quad (1.1200) \quad (.0008813) \quad (.00016868)$$

Adj. $R^2 = 0.18$, $n = 432$

where

Q = average residential water consumption measured in a community in 100 cubic feet (ccf) per month;

P = price of water paid by the household, measured in dollars per ccf;

Y = is the annual per capita income, measured in thousands of dollars and deflated by the consumer price index (CPI); and

C = is a climatic variable.

The standard errors are listed in parentheses.

The adjusted R^2 for the linear demand model indicates that only 18 percent of the variation of water consumption is explained by P, Y and C. All the coefficients are statistically significant from zero at the 0.05 confidence level except for the coefficient of P.

Elasticities computed from the aggregate pooled data are presented in Table 2. The estimated price elasticity calculated at the means of consumption and price from the linear demand model is -.037; but, to repeat, price is statistically insignificant. This estimated price elasticity implies that a 1 percent increase in price would cause the quantity demanded to decrease by approximately 0.04 percent. Such an estimate is below the elasticities in most water demand studies, which range from -.15 to -.73.

The estimated income elasticity calculated at the means of consumption and income for the linear demand model is 1.57. This means that for a 1 percent increase in per capita monthly income

TABLE 2 Summary of Elasticity Estimates Utilizing Aggregate Pooled Data

Aggregate Data	Price	Income	Adj.R^2
	-.037	1.57*	.18
Seasonal Aggregate Data			
Summer	-.160	1.74**	.17
Winter	-.047	1.69**	.26

* Significant at the .05 level.
** Significant at the .01 level.

the quantity demanded for water increases by 1.57 percent.

The climate variable, C performed remarkably well and is of the expected sign. The climate variable produced results that are similar to those of Griffin and Chang (1990).

Seasonal price elasticity estimates were calculated by reestimating the water demand model for parts of the year and adding price-climate cross products as suggested by Griffin and Chang (1990). The general demand model used to estimate seasonal residential water demand is as follows:

$$Q = b_0 + b_1P + b_2C + b_3PC + b_4Y + u$$

Summer is defined to include the months of April to October, while winter includes the months from November to March. Regressions based on the summer and winter residential consumption again indicated significant autocorrelation and heteroskedasticity. After correcting for autocorrelation and heteroskedasticity, the results of the summer and winter water demand model are as follows:

$$Q_s = -8.9436 - 1.4220\ P + 0.0016853\ C - 0.0003025\ PC + 0.01688\ Y$$

(8.4082) (7.4318) (0.0046) (0.0041) (0.0011)

Adj. $R^2 = 0.17$, n = 252

$$Q_w = -6.6702 - 0.37959\ P + 0.002587\ C - 0.002008\ PC + 0.01469\ Y$$

(6.9188) (5.8548) (.007197) (.6162) (0.0014)

Adj. $R^2 = 0.2580$, n = 160

where:

PC = the price-climate cross products.

The standard errors are listed in parentheses.

The adjusted R^2 for the summer linear demand model indicates that 17 percent of the variation of water consumption is explained by P, C, PC and Y. The summer coefficients of P and C are statistically insignificant. In the summer model, the coefficients of Y is significant at the 1 percent level.

The adjusted R^2 for the winter linear demand model indicates that 26 percent of the variation of water consumption is explained by P, C, PC and Y. The winter coefficients of P and C are statistically insignificant. The coefficient of Y in the winter is significant at the 1 percent level.

Based on the preceding estimates, the price elasticities of demand calculated at the means of consumption and price from the linear demand models are -.16 for summer, and -.04 for winter. However, both summer and winter coefficients of price are statistically insignificant, so the elasticity estimates do not warrant much confidence. The estimated price elasticities are consistent with the hypothesis that summer water demand is more price responsive than winter demand as found by Griffin and Chang (1990).

The estimated income elasticity calculated at the means of consumption and income for the linear demand model is 1.74 for the summer model and 1.69 for the winter model. Seasonal pooled aggregate data elasticities are presented in Table 2.

The effect of pooling 4 communities is investigated by utilizing the F-statistic described in the methodology chapter. The F-statistic for pooling is calculated to be 146.89. The F statistic for the hypothesis to pool is 1.00 at the 0.01 significance point.

This provides strong evidence against pooling the data.

This result may be explained by the fact that residential customers in Bloomington and Danville face uniform water rates while residential customers in Rantoul and Normal face declining block rates. Moreover, the four communities have very different underlying economic structures. Therefore, the next step is to test if communities should be pooled by the type of water rate structure.

The F-statistic calculated from pooling the communities of Bloomington and Danville is 238.08, while the calculated F statistic from pooling the communities of Rantoul and Normal is 21.68. Again, both results suggest that there is strong evidence not to pool the data. Given these results, in what follows, we look at each community individually.

B. Community Level Results

Residential water demand were estimated separately for the communities of Bloomington, Danville and Rantoul. The regression for the community of Normal is not presented because none of the estimated coefficients were different from zero at conventional levels of statistical significance. Correcting for autocorrelation and heteroskedasticity, the results of the demand models for Bloomington, Danville and Rantoul are as follows:

$$Q_B = 21.564 - 5.319\ P_B - 0.00424\ Y_B + 0.0020895\ C_B$$

$$(3.244)\ (3.1013)\quad (0.002853)\quad (0.000374)$$

Adj. $R^2 = 0.38$, $n = 108$

$$Q_D = 8.0261 - 4.1288\ P_D + 0.002373\ Y_D + 0.0010034\ C_D$$
$$(4.7503)\ (1.6289)\quad (.00376803)\quad (.0002133)$$
Adj. $R^2 = 0.24$, n = 108

$$Q_R = 2.3252 + 1.2011\ P_R + 0.0015857\ Y_R + 0.001361\ C_R$$
$$(1.0751)\ (1.0597)\quad (.000971)\quad (.000120)$$
Adj. $R^2 = 0.37$, n = 108

The standard errors are listed in parentheses.

The adjusted R^2 for all three community data sets increased in comparison to the adjusted R^2 calculated from the pooled cross-section time series. For Bloomington the adjusted R^2 for the linear demand model for Bloomington indicates that 38 percent of the variation of water consumption is explained by P, Y and C. The coefficient of P is significant at the 5 percent level. The coefficient of Y did not have the expected sign and is significant at the 10 percent level. The coefficient of C was significant at the 1 percent level.

The adjusted R^2 for the linear demand model for Danville was calculated to be 24 percent. The coefficient of P is also significant at the .05 level. The coefficient of Y has the expected sign but was statistically insignificant. The coefficient of C was significant at the .01 level.

Finally for Rantoul, the adjusted R^2 for the linear demand model was calculated to be 37 percent. The coefficient of P did not have the expected sign and was also statistically insignificant. The coefficient of Y had the expected sign but was statistically insignificant. The coefficient of C was significant at the .01 level.

The elasticities computed from the coefficient estimates are summarized in Table 3. The estimated price elasticities calculated at the means of consumption and price are: -.43 for Bloomington and -.61 for Danville. These are within the range identified in studies of other communities. The price elasticity for Rantoul is not presented because the coefficient of P did not have the expected sign and was not significant at the conventional level.

The estimated income elasticities calculated at the means of consumption and income are .31 for Danville and .22 for Rantoul. Both Danville and Rantoul coefficients of income are statistically insignificant. The income elasticity for Bloomington is not presented because the coefficient of Y did not have the expected sign and was not statistically significant.

C. Discussion

The water demand model utilizing pooled cross-section and time-series data of aggregate monthly residential consumption produce mixed results. The value of the adjusted R^2 for the linear demand model is only 18 percent. Except for the coefficient of price, all the estimated coefficients are significantly different from zero. Although price is insignificant, the estimated price elasticity of approximately -.04 is consistent with the conclusion of inelasticity of water demand reported in most studies, but it is

TABLE 3 Summary of Aggregate Community Elasticity Estimates

	Price	Income	Adj.R^2
Bloomington	-.43*	---	.38
Danville	-.61*	.31	.24
Rantoul	---	.22	.37

* Significant at the .05 level.

Note: The values for income elasticity for Bloomington and price elasticity for Rantoul are not presented because the coefficients did not have the expected signs.

far below the elasticity range of -.15 to -.73 reported in most studies. The estimated income elasticity is 1.57 which is among the higher estimates reported in other studies. Estimated summer and winter price elasticities exhibit seasonal variability, but both summer and winter price coefficients are statistically insignificant.

All these results suggest that pooling this particular data set is inappropriate. To test this proposition we undertook a pooling test utilizing an F-statistic (Madalla 1977, 323). The F statistic is calculated to be 88.25, which suggests that there is strong evidence not to pool the data. Pooling communities by the type of water rate structure is subsequently tested. The results again indicate that there is strong evidence not to pool the data.

Since it appears inappropriate to pool these communities, we estimated residential water demand separately for the communities of Bloomington, Danville and Rantoul. The adjusted R^2s of each of these three communities are considerably higher than the estimated R^2 of the water demand model based on the pooled cross-section time series data of residential water consumption. Except for Rantoul, the price coefficients for Bloomington and Danville are statistically significant. The income coefficients for each of the three communities are statistically insignificant. On the other hand the climate coefficients for each of the three communities are all statistically significant. The estimated price elasticities of -.43 for Bloomington and -.61 for Danville all lie within the range of price elasticities reported in other studies. The estimated income elasticities of .31 for Danville and .22 for Rantoul also all lie within the range of income elasticities reported in other studies. Therefore, all these results suggest that a demand model for each individual community provides a better approximation of water demand than the demand model utilizing the pooled sample.

D. General Demand Model with Household Data

Pooled household cross-section data of bi-monthly residential consumption in five communities were used in the first regression. The augmented general demand model is:

$$Q = b_0 + b_1AP + b_2PO + b_3Y + b_4C + b_5N + b_6T + b_7S + u$$

In communities with block rate price structures, after checking each individual's household water consumption record, it was observed that household water consumption fell within the first block . As a result, the first block price water rate was selected. The estimated price, income, climate, toilet and shower coefficients had the expected signs and the results were statistically significant. The initial results however indicated significant autocorrelation and heteroskedasticity. After correcting for autocorrelation and heteroskedasticity, the results of the water demand model are as follows:

$$\underset{(0.58692)}{Q = 1.5071} - \underset{(0.209380)}{1.4277\ P} + \underset{(0.000006296)}{0.000028241\ Y} + \underset{(0.00013804)}{0.00041957\ C} +$$

$$\underset{(0.08213)}{2.9643N} + \underset{(0.20159)}{0.79538\ T} + \underset{(0.22998)}{1.5293\ S}$$

Adj. $R^2 = 0.1974$, $n = 3079$

where

Q = is per residential water consumption measured in 100 cubic feet (ccf) per 2 months;

P = price of water paid to the household;

Y = is the annual household income for 1990, measured in thousands of dollars;

C = is a climatic variable;

N = is the number of persons in the household;

T = the number of flush toilets; and

S = the number of showers or tubs in the house.

The standard errors are listed in the parentheses.

The adjusted R^2 for the linear demand model indicates that approximately 20 percent of the variation in the water consumption is explained by P, Y, C N, T and S. All the coefficients are statistically significant from zero in the linear demand model with the expected signs. The coefficients of P, Y, C, N, T and S in the linear demand model are significant at the 1 percent level.

The estimated price elasticity calculated at the means of consumption and price from the linear household demand model is -.14. This implies that for a 1 percent increase in price would cause the quantity demanded to decrease by approximately .14 percent.

The estimated income elasticity calculated at the means of consumption and income for the linear demand model is .0759. This means that for a 1 percent increase in annual per capita income the quantity demanded for water would increase by .0759 percent.

Similar to the results from the regressions using the aggregate data, the climate variable, C, again performed well and is of the expected sign.

The household size variable, H, is of the expected sign and also performed as expected.

The number of flush toilets, T, and the number of showers or tubs, S, are of the expected sign and performed as expected. An increase in the number of flush toilets and the number of showers would result in an increase in the consumption of water.

Nested hypotheses tests for the augmented general water demand model are conducted by using the Wald Chi-Square statistic. Testing the two nested hypotheses will determine whether all the variables should be included in the augmented general water demand model. The first nested hypothesis tested is:

$$H_0 : b_H, b_T, b_S = 0$$

A second regression using the following variables: P, Y and C was performed. After correcting for autocorrelation and heteroskedasticity, the results of the water demand model are as follows:

$$Q = 8.7856 - 1.6413 P + 0.00011763 Y + 0.0010033 C$$

$$(0.65398)(0.25260) \quad (0.000006308) \quad (0.00016639)$$

Adj. $R^2 = 0.0827$, $n = 3079$

The standard errors are listed in the parentheses.

The value of the Wald Chi-Square statistic for the first nested hypothesis is 1537.32 with three degrees of freedom. The Wald Chi-Square statistic for the null hypothesis to pool with three degrees of freedom at the 0.01 significance point is 11.3. The result suggests there is strong evidence to include all the variables in the general water demand model.

The adjusted R^2 for the linear demand model indicates that only 8.27 percent of the variation in the water consumption is explained by P, Y and C. All the coefficients are statistically significant from zero in the linear demand model. The coefficients of P, Y and C in the linear demand model are significant at the .01 percent level.

The estimated price elasticity calculated at the means of consumption and price from the linear demand model is -.16. This estimate implies that 1 percent increase in price would cause the quantity demanded to decrease by approximately .16 percent.

The estimated income elasticity calculated at the means of consumption and income for the linear demand model is .316. This means that for a 1 percent increase in annual per capita income the quantity demanded for water would increase by .316 percent.

The second nested hypothesis tested is:

$H_0 : b_T, b_S = 0$

A third regression using the same variables was performed but with the deletion of two variables: T and S. The initial results were statistically significant and the estimated price, income, climate and the household size coefficients had the expected signs. However, again the initial results indicated significant autocorrelation and heteroskedasticity. After correcting for autocorrelation and heteroskedasticity, the results of the water demand model are as follows:

$$Q = 3.4667 - 1.4787\,P + 0.000078891\,Y + 0.00043956\,C +$$
$$(0.6137)\quad(0.22670)\quad(0.000005784)\quad(0.00014903)$$
$$2.9776\,H$$
$$(0.087587)$$

Adj. $R^2 = 0.1997$, $n = 3079$

Table 4 summarizes the elasticity estimates.

The value of the Wald Chi-Square statistic for the second nested hypothesis is 162.38 with two degrees of freedom. The Wald Chi-Square statistic for the null hypothesis to pool with two degrees of freedom at the 0.01 significance point is 9.21. Again, the result suggests there is strong evidence to include all the variables in the general water demand model.

With the deletion of the toilet and shower variables, the R^2 is roughly the same as in the augmented household model. Approximately 20 percent of the variation in the water consumption is explained by P, Y, C and H. Again, all the coefficients are statistically significant from zero at the .01 level. The estimated price elasticity calculated at the means of consumption and price from the linear demand model is -.145, which is approximately the same as in the augmented model.

The estimated income elasticity calculated at the means of consumption and income for the linear demand model is .2121. A 1 percent increase in annual per capita income would lead to a .21 percent increase in the quantity demanded. Again, the third regression with the deletion of the toilet and shower variables

TABLE 4 Summary of Pooled Household Elasticity Estimates

	Price	Income	Adj. R^2
Augmented Demand Model	-.14**	.07**	.20
Nested Hypothesis 1	-.16**	.32**	.08
Nested Hypothesis 2	-.15**	.21**	.19

** Significant at the .01 level.

produce a greater estimate of elasticity than the first household model.

The effect of pooling is investigated by utilizing the F statistic described earlier in the section on Methodology. In analyzing pooling, only three of the five communities were used. The Rantoul and Danville households were dropped because there was no variation in their respective prices. The F-statistic is calculated to be 10.015. The F-statistic for the hypothesis to pool is 2.32 at the 0.01 significance point. This suggests that there is strong evidence not to pool the data. The result that pooling is inappropriate for this particular set of data is similar to the findings of the study conducted by Griffin and Chang (1990).

E. Discussion

The general water demand model was augmented with several socio-economic variables for more detailed analysis of the pooled household cross-section data of bi-monthly consumption. The value of the adjusted R^2 for the linear demand model is approximately 20 percent. All the coefficients are statistically significant from zero with the expected signs in the linear demand model. Except for the coefficient of price, all the estimated coefficients are significantly different from zero. The estimated price elasticity is -.14 which approximately falls within the reported elasticity range of -.15 to -.73 reported in most studies and is again consistent with the reported conclusion of inelasticity of water demand. The estimated income elasticity is .0759 which is far below the reported range of 0.11 to 2.14 reported in other studies.

Nested hypotheses tests for the augmented general water demand model are conducted by using the Wald Chi-Square statistic. Testing the two nested hypotheses determined whether all the variables should be included in the augmented general water demand model.

In testing the first nested hypothesis, the value of the Wald Chi-Square statistic is calculated to be 1537.32 with three degrees of freedom which suggests that is strong evidence to include all the variables in the general water demand model. The adjusted R^2 for the linear demand model is only 8.27 percent which is far below the reported value of the adjusted R^2 of the augmented linear demand model. Again all the coefficients are statistically significant from zero. The estimated price elasticity is -.16. The estimated income elasticity is .316 which is far greater than the reported income elasticity of the augmented linear demand model.

Testing the second nested hypothesis, the value of the Wald Chi-Square statistic is 162.38 with two degrees of freedom. This again suggests that there is strong evidence to include all the variables in the general water demand model. The adjusted R^2 for the linear demand model is approximately 20 percent which is roughly the same as the adjusted R^2 of the augmented linear demand model. Again, all the coefficients are statistically significant from zero. The estimated price elasticity is -.145 which is approximately the same as in the augmented model. The estimated income elasticity is .2121 which again is greater than the reported income elasticity of the augmented linear demand model.

The effect of pooling is investigated by undertaking a pooling test described earlier. The F-statistic is calculated to be 10.015, which suggests that there is strong evidence not to pool the data.

F. Comparison of Results of the General Demand Models with Aggregate Data and Household Data

Differences in the aggregate and household data sets should again be reiterated. The general demand model with aggregate data was based on the pooled cross-section for four communities and a time-series data set from 1981-1989 of aggregate average monthly residential consumption. On the other hand, the general demand model with household data was based on pooled household cross section data for five communities of bi-monthly residential consumption for 1990. Therefore, the comparisons of the results of the general model with the two data sets should be viewed with caution.

The comparison of results of the general demand models with aggregate data and household data are presented in Table 5. In terms of the R^2, the general demand model utilizing aggregate data has an R^2 of .18 which is approximately twice as large than the R^2 of.0827 of the general demand model using the household data.

The coefficients of P,Y and C are all statistically significant from zero in the general demand model using the household data. In the case of the general demand model utilizing the aggregate data, all the coefficients are statistically

TABLE 5 COMPARISON OF RESULTS OF THE GENERAL DEMAND MODELS WITH AGGREGATE DATA AND HOUSEHOLD DATA

	Price	Income	Adj.R^2
General Demand Model (Aggregate Data)	-.037	1.57*	.18
General Demand Model (Household Data)	-.11**	.32**	.08

* Significant at the .05 level.
** Significant at the .01 level.

significant from zero except for the coefficient of P.

The estimated price elasticity of the general demand model based on the pooled aggregate data is -.037 but again it should be reiterated that price is statistically insignificant. On the other hand, the estimated price elasticity of the general demand model based on the pooled household data is -.16 which is close to the range of price elasticities reported in most studies.

The estimated income elasticity of the general model based on the pooled aggregate data is 1.57 which is much greater than the estimated income elasticity of .316 of the general demand model based on the pooled household data. The wide disparity in income elasticity may be attributed to the fact that annual per capita income was used in the general demand model using pooled aggregate data while estimated household income by the head of the household was used in the general demand model utilizing the pooled household data.

Finally, in terms of testing the effect of pooling, the general demand models utilizing both data sets strongly suggested that pooling is inappropriate.

CHAPTER 5

CONCLUSIONS

The section on conclusions is divided into parts: (A) determinants of water demand in central Illinois and (B) comparability of data.

A. Determinants of Water Demand in Central Illinois

In the Introduction of this study, it was stated that most municipal water utilities have assumed that aggregate water demand was simply a function of population and was almost unrelated to the price of water. With the aid of economic theory, determinants of water demand have been identified and statistically tested for the communities studied in central Illinois.

First, the study suggest mixed things about the relationship between the quantity of water demanded and the price of water. Estimates of price elasticity are negative and less that unitary based on the types of data used. The estimated price elasticity based on the pooled aggregate data is -.037 and insignificant, which implies that aggregate water demand is very slightly affected by the price of water if at all. However, using aggregate data for Bloomington and Danville, the estimated price elasticities are -.43 and -.61 respectively. Also, using the pooled household data, the estimated price elasticities are in the range -.14 to -.16. The disparities in price elasticity estimates seem to depend on the type of data used and from which specific community the data were obtained.

For water system managers, these results taken together have two important implications: (1) Generally the estimates although not universally, indicate inelastic water demand with respect to prices. This implies that price must be raised significantly to bring about much of a reduction in use. An increase in price when the demand of water is inelastic will significantly increase water revenues; (2) The variation in price elasticity estimates among the different communities suggest differences in underlying preferences. The different estimates imply potentially important differences in the degree to which prices would have to be raised by the water system manager for each community to accomplish a particular percentage reduction in water consumption.

Consumer incomes also affect the quantity of water demanded. Based on the pooled aggregate and household data used in this study, the coefficients of income were found to be statistically significant. Estimated income elasticities for central Illinois households are positive. Again, there is a wide disparity in the estimates of income elasticity based on the type of data used. The estimated income elasticity based on the pooled aggregate data is 1.57 while the estimated income elasticity based on the pooled household data ranges from .0759 to .316. The results based on the pooled aggregate data suggest elastic demand for water with respect to income; growth in real income and water consumption would make water an increasing proportion of budgets of households. This is inconsistent with the findings of most other studies. More similar to the other studies are the results based on the pooled household data suggest inelastic demand for water with respect to income. This implies that growth in real income should bring about an increased water consumption, but water costs would compose a declining proportion of household budgets. Further analysis is needed to understand better the differences in income elasticity and their implications.

Climatic factors also influence water demand. In this study, the climate variable used in the general water demand model captures the changes in temperature and precipitation for each community studied. The coefficients of the climate variable are statistically significant for the two data sets used.

The findings suggest that the demand in Central Illinois for water in summer is more responsive to changes in price than in winter. It means this result is consistent with findings for less humid areas. Price would not have to be changed as significantly during the summer to bring about a particular proportionate reduction in use as compared to winter.

Finally, changes in water-using technology (e.g flush toilets, tubs or showers) have an effect on the demand for water. Based on the pooled aggregate data in this study, the coefficients of water-using technology are found also to be statistically significant. Increases in water-using technology cause water consumption to increase.

B. Comparability of Data

In comparing the results of the general demand model based on the pooled aggregate data and the pooled household data, there is wide disparity in the values of the estimated price and income elasticities. The reasons for the differences are not immediately apparent and warrant further investigation.

Finally, the results suggest that pooling is inappropriate for both data sets in this study. This implies that it is more appropriate to estimate water demand for a single site than an area or region. Further analysis of the data is required before firm conclusions can be drawn. However, if the elasticity estimates do indeed vary widely from place to place, it would mean that management strategies need to be carefully tailored to local circumstances. This issue lies ahead for future research.

REFERENCES

Agthe, D.E.,B.R.Billings,J.L.Dobra and K.Raffie. "A Simultaneous Equation Model for Block Rates." *Water Resources Research*, (22), 1-4, 1986.

Al-Qunaibet, M.H., and R.S. Johnston. "Municipal Demand for Water in Kuwait: Methodological Issues and Empirical Results." *Water Resources Research,* 21(4), 433-438, 1985.

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

Chicoine, D.L., M.R. Grossman, and J.A. Quinn. "Rural Water Districts in Illinois." Illinois Water Resources Center, University of Illinois, PB84-22723, 1984.

Chicoine, D. L., S. Deller, and G. Ramamurthy. "Water Demand Estimation Under Block Rate Pricing: A Simultaneous Equation Approach." *Water Resources Research*, 22(6), 859-863, 1986.

Chicoine, D. and G. Ramamurthy. "Evidence on the Specification of Price in the Study of Domestic Water Demand." *Land Economics*, 62(1), 26-32, 1986.

Danielson, L.E. "An Analysis of Residential Demand for Water Using Micro Time-Series Data." *Water Resources Research*, 763-767, August 1979.

Dzigielewski, B., J.J. Boland, and D.D. Baumann. "An Annotated Bibliography on Techniques of Forecasting Demand for Water."*IWR-Report 81-CO3*, U.S Army Corps of Engineers, Institute for Water Resources, Fort Belvoir, Virginia, 1981.

Dziegielewski, B., and J.J. Boland. "Forecasting Urban Water Use: The IWR-Main Model." *Water Resources Bulletin*, 25(1), 101-109, 1989.

Griffin, A.H. and W.E. Martin. "Price Elasticities for Water: A Case of Increasing Block Rates: Comment." *Land Economics,* 57(2), 266-275, 1981.

Griffin, A.H. and W.E Martin. "Comment on 'Dynamic Models of Residential Water Demand'." *Water Resources Bulletin*, 18(1), 187-190, 1982.

Griffin, R.C. and C. Chang."Pretest Analysis of Water Demand in Thirty Communities." 26(10) 2251-2255, October 1990.

Griffin, R.C. and C. Chang."Seasonality in Water Demand." *Western Journal of Agricultural Economics*, 16(2), 207-217, 1991.

Hanke, S. and L. de Mare. "Residential Water Demand: A Pooled, Time Series, Cross section Study of Malmo, Sweden." *Water Resources Bulletin*, 621-25, August 1982.

Howe, C.W., and F.P. Linaweaver, Jr."The Impact of Price on Residential Water Demand and Its Relation To System Design and Price Structure." *Water Resources Research*, 3(1) 13-31, 1967.

Howe, C.W."Impact of Price on Residential Water Demand:Some New Insights." *Water Resources Research*, 713-716, August 1982.

Jones, C.V., and J.R. Morris. "Instrumental Price Estimates and Residential Water Demand." *Water Resources Research*, 20(2), 197-202, 1984.

King, R.A. "Choices and Consequences." *American Journal of Agricultural Economics*, 61(5), 839-848, 1979.

Maddala, G.S. *Econometrics*, McGraw-Hill, New York, 1977.

Madalla, G.S. *Introduction to Econometrics*, Macmillan, New York, 1988.

Martin, W.E., H.M. Ingram, N.K Laney, and A.H. Griffin, *Saving Water in a Desert City*, Resources for the Future, Washington, DC, 1984.

Martin, W.E., and J.F.Thomas. "Policy Relevance in Studies of Urban Residential Water Demand." *Water Resources Research*, 22(13) 1735-1741, 1986.

Martin, W.E., and S.Kulawkowski. "Water Price as a Policy Variable in Managing Urban Water Use: Tucson, Arizona." *Water Resources Research*, 27(2), 157-166, 1991.

Moncur, J.E.T. "Drought Episodes Management: The Role of Price." *Water Resources Bulletin*, 25(3), 393-398, 1987.

Nordin, J.A. "A Proposed Modification on Taylor's Demand Analysis: Comment." *The Bell Journal of Economics*, Spring, 74-110, 1975.

Nieswiadomy, M.L. and D.J. Molina "Urban Water Demand Estimates Under Increasing Block Rates." *Growth and Change: A Journal of Urban and Regional Policy*, 1-12, Winter, 1988.

Nieswiadomy, M.L. and D.J. Molina "Comparing Residential Water Demand Estimates Under Decreasing and Increasing Block Rates Using Household Data." *Land Economics*, 65, 280-289, 1989.

Polzin, P.E. "The Specification of Price in Studies in Consumer Demand Under Block Price Scheduling: Additional Empirical Evidence." *Land Economics*, 60, 303-309, 1984.

Polzin, P.E. "The Specification of Price in Studies in Consumer Demand Under Block Price Scheduling: Reply." *Land Economics*, 61, 300-301, 1985.

Schefter, J.E, and E.L.David. "Estimating Residential Water Demand Under Multi-part Tariffs Using Aggregate Data." *Land Economics*, 61, 272-280, 1985.

Shen, II. J., "The Efficiency of Water Pricing vs. Regulation During Drought: Bloomington, Illinois." (Unpublished) M.S. Thesis, Illinois State University, Normal, Illinois, 1991.

Stevens, T.H., G. Adams, and C. Willis. "The Specification of Price in Studies of Consumer Demand Under Block Price Scheduling: Comment." *Land Economics*, 61, 327-329, 1985.

Taylor, L.D."The Demand for Electricity: A Survey." *The Bell Journal of Economics*, Spring 74-110,1975.

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

Appendix 1
Preliminary Survey of Water Utilities

Dear

With the support of the Water Resources Center at the University of Illinois, I am conducting a study of water consumption in central Illinois. I am writing to request your cooperation in this research.

The study aims to determine the sensitivity of water consumption to social and economic influences. It will have two phases. The first phase will analyze aggregate data on water consumption by user categories (e.g., residential). the second phase will employ data for individual users. This structure will permit comparisons of two approaches.

To be successful, the study will need your cooperation in making the data available. Some of the data you may be able to send at this time. This would help us greatly. A large return envelope is enclosed for your use. Alternatively, my colleagues and I would visit your office at a convenient time to collect the data that you cannot send. As a cooperator, I would make sure that your utility receives the final report.

Enclosed is a short survey for information about how you collect water consumption data, your pricing structure, and other preliminary information. I would be grateful if you or your representative could return the completed survey and related data in the stamped return envelope. We hope to hear from you by Friday, November 16. If you have any questions, please free to call me at (217) 333-1253.

Thank you very much for your consideration.

Sincerely,

John B. Braden
Professor

JBB:pb

Enclosure

University of Illinois
Department of Agricultural Economics

DEMAND FOR WATER IN CENTRAL ILLINOIS

PRELIMINARY SURVEY OF WATER UTILITIES

1. Name of Water Utility:_______________

2. Do your water bills include charges for sewerage? (check one)
Yes____ No____

3. Do your records on water sales allow the identification of the amount being sold to residential users (as distinguished from, industrial, commercial, or government users)? (check one)
Yes____ No____

4. How frequently are water meters read (check one)
Monthly____ Bimonthly____ Other____

5. Has water conservation been required or strongly encouraged by city officials or the water utility at any time since 1979? (check one) Yes____ No____

6. Would you permit access to the water sales records of specific residential users in your service area for confidential use in our research? (check one) Yes____ No____

   Would it make a difference in your answer to the preceding question if we could obtain the written permission of the residential users? (check one) Yes____ No____

(Please continue on the next page)

7. The types of data listed below are needed in our research. We will be very grateful if you can send some or all of these data to us along with this survey in the enclosed, stamped return envelope. Alternatively, we would like to visit your office at a convenient time to gather the data. Please indicate whether you are sending the data or would make the data available at your office:

Data type:	Sending with Survey	Available at Our Office
	(check one)	
Water Rate Schedules (as available for 1979-present)	____	____
Total Water Sales (as available for 1979-present)	____	____
Water Sales by User Category (e.g., residential, industrial) (as available, monthly for 1979-present)	____	____
Population served(1979-present)	____	____
Number of Hook-ups by Size (as available for 1979-present)	____	____
Information on Water Conservation Requirements or Campaigns(1979-present)	____	____

8. Please indicate the name, address, and phone number of the person who responded to this survey (clearly please):

________________ Phone:________

____

____

Please return this survey in the enclosed, stamped, addressed envelope, or mail to: Dr.John B. Braden, WRCS, Department of Agricultural Economics, University of Illinois, 1301 W. Gregory Drive, Room 305, Urbana, IL 61801

THANK YOU FOR YOUR ASSISTANCE!

Appendix 2
Household Questionnaire

Dear Head of Household:

Good water is vital to the people of Illinois. The University of Illinois is conducting a survey on residential water consumption in Illinois communities. This survey will contribute to future plans for protecting and enhancing community water supplies. It is part of a research project supported by the Illinois Water Resources Center and led by Professors John Braden and William Martin.

You can help with this survey by answering the questions on the following pages. There aren't many questions and you will probably be able to answer them in just a few minutes. Your answers should be given on the survey form.

A very important part of this survey is your willingness for the water supplier in your community to release for our records on your household water consumption in calendar years 1989-1990. Your written permission is required. If you are willing, please be sure to sign on the line in question 1. Your cooperation will be very much appreciated.

A pre-addressed, postage-paid reply envelope is include for your use. Just place the survey in the envelope, seal the envelope and place it in the mailbox. We hope to receive your reply within a few days.

In appreciation for the cooperation of households in your community, two will be selected to receive a cash prize of $50 each. In order to be considered, we must receive your response by July 26, 1991. The winners will be selected at random in a drawing and notified by August 26, 1991. If you would like to participate, please provide your name, address, phone number, and social security number on the separate "PRIZE" form accompanying your survey instrument and sent that form in the same return envelope with your survey response.

Sincerely yours

John B. Braden
Professor

HOUSEHOLD WATER CONSUMPTION SURVEY

Thank you for answering the following questions about your household. There are just a few questions and you will probably be able to complete this survey in a very short time.

With the exception of the response to question 1, all your answers will be kept strictly confidential.

1. Do you agree to permit your residential water supplier to release these records on the water consumption for calendar years 1989 and 1990? (Circle "yes" or "no" and follow the related instructions.)

Yes ---> Please sign the name and print your name and address below:

Signature: ______________________

Name (Print): ______________________

Address: ______________________

City: ______________________

Now, go on to the remaining questions.

No---> Please go on to the remaining questions.

(CIRCLE ONE)

2. How many full years have you lived in your home(do not count partial years?
(If less than one full year, circle zero.) 1 2 3 4 5 6

(1)0 (2)1 (3)2 (4)3 (5)4 (6)5-or more

3. How many people 16 or older currently live in your household? 1 2 3 4 5

(1)1 (2)2 (3)3 (4)4 (5)5 or more 1 2 3 4 5

4. How many people 15 or younger currently live in your household? 1 2 3 4 5 6 7 8

(1)0 (2)1 (3)2 (4)3 (5)4 (6)5 (7)6 (8)7 or more

5. What is the age of the head of the household?
____years

6. How many flush-toilets are in your residence?

(1)1 (2)2 (3)3 (4)4 or more 1 2 3 4

7. How many tubs or showers are in your residence?

(1)1 (2)2 (3)3 (4)4 or more 1 2 3 4

8. Do you wash clothes in a washing machine in your residence? 1 2

(1)Yes (2)No

9. Do you have a dishwasher in your residence? 1 2

(1)Yes (2)No

10. Do you have responsibility to maintain the yard around your residence? 1 2

(1)Yes ---> Go to question 11.

(2)No ---> Go to question 12.

11. Do you use water purchased from your water utility for watering a lawn or garden? 1 2

(1)Yes (2)No

12. In the summer months, how many hours on average do you water your lawn, trees, or garden <u>each week</u>? 1 2 3 4
(Circle one range of hours.)

(1)1-5 (2)6-10 (3)10-15 hrs. (4)16 or more hrs.

13. How many automobiles are operated by your household? 1 2 3 4 5

(1)0 (2)1 (3)2 (4)3 (5)4 or more

14. How many automobiles do you wash <u>at your residence each week</u>, on average, during warm weather seasons? 1 2 3 4 5

(1)0 (2)1 (3)2 (4)3 (5)4 or more

15. Do you have a swimming pool at your residence (excluding small, portable pools)? 1 2

(1)Yes (2)No

16. What was the total income from all sources before taxes of your household in 1990? (Circle the code code for the appropriate income range.) 1 2 3 4 5 6 7 8

(1)Less than $10,000	(2)$40,000-$49,999
(2)$10,000-$19,999	(6)$50,000-$59,999
(3)$20,000-$29,999	(7)$60,000-$69,999
(4)$30,000-$39,000	(8)$70,000 or more

After you have answered all questions, please put this survey form back into the envelope in which it came in and place the envelope in the mail.

THANK YOU FOR YOUR COOPERATION!

Appendix 3

Results of the Administration of Household Water Consumption Survey in Several Central Illinois Communities

Community	Number of Surveys Sent	Number of Correctly Completed Returned Surveys	Percentage of Returned Surveys
Bloomington	330	94	28.5%
Champaign-Urbana	349	144	41.3%
Danville	334	128	38.3%
Decatur	339	127	37.5%
Normal	349	145	41.5%
Rantoul	344	143	41.6%

Appendix 4
Water Rate Schedules

Rantoul

February 22, 1980	Residential/Commercial 1st 15,000 gallons $1.40/1000 gallons Next 35,000 gallons $1.25/1000 gallons Next 50,000 gallons $1.15/1000 gallons All over 100,000 gallons $.93/1000 gallons Air Conditioning and Lawn Sprinkling $.90 per 1000 gallons. Available April through October only.
November 1, 1981	Residential $1.40 per 1000 gallons Commercial, Industrial, Village, Air Conditioning, Lawn Sprinkling, Federal Government 1st 80,000 gallons $1.40/1000 gallons All over 80,000 gallons $1.10/1000 gallons
November 1,1983	Residential $1.65 per 1000 gallons All other users 1st 80,000 gallons $1.65/1000 gallons All over 80,000 gallons $1.35/1000 gallons
July 1, 1986	Residential $1.75 per 1000 gallons All other users 1st 80,000 gallons $1.75/1000 gallons All over 80,000 gallons $1.55/1000 gallons
November 1, 1987	All users $2.00 per 1000 gallons

Danville

December 24, 1980

		Cubic Feet Per Month	Rate per 100 Cu.Ft.
Step 1	First	10000	.95
Step 2	Next	90000	.57
Step 3	Next	900000	.39
Step 4	Over	1000000	.309

August 23, 1982

		Cubic Feet Per Month	Rate per 100 Cu.Ft.
Step 1	First	10000	1.13
Step 2	Next	90000	.73
Step 3	Next	900000	.50
Step 4	Over	1000000	.404

January 20, 1983

		Cubic Feet Per Month	Rate per 100 Cu.Ft.
Step 1	First	10000	1.80
Step 2	Next	90000	.78
Step 3	Next	900000	.54
Step 4	Over	1000000	.435

February 27, 1986

		Cubic Feet Per Month	Rate per 100 Cu.Ft.
Step 1	First	10000	1.16
Step 2	Next	90000	.74
Step 3	Next	900000	.54
Step 4	Over	1000000	.48

December 14, 1989

		Cubic Feet Per Month	Rate per 100 Cu.Ft.
Step 1	First	10000	1.23
Step 2	Next	90000	.74
Step 3	Next	900000	.54
Step 4	Over	1000000	.48

Bloomington

May 22, 1973

		Cubic Feet Per Month	Rate per 100 Cu.Ft. Inside City	Outside City
Step 1	First	2300	.88	1.27
Step 2	Next	11700	.59	1.04
Step 3	Next	486000	.42	.69
Step 4	Over	500000	.26	.64

April 13, 1982

		Cubic Feet Per Month	Rate per 100 Cu.Ft. Inside City	Outside City
Step 1	First	2300	1.12	1.61
Step 2	Next	11700	.75	1.31
Step 3	Next	486000	.53	.87
Step 4	Over	500000	.34	.81

January 1, 1986

		Cubic Feet Per Month	Rate per 100 Cu.Ft. Inside City	Outside City
Step 1	First	2300	1.29	1.85
Step 2	Next	11700	.86	1.51
Step 3	Next	486000	.61	1.00
Step 4	Over	500000	.39	.93

January 1, 1987

		Cubic Feet Per Month	Rate per 100 Cu.Ft. Inside City	Outside City
Step 1	First	2300	1.35	1.94
Step 2	Next	11700	.90	1.59
Step 3	Next	486000	.64	1.05
Step 4	Over	500000	.41	.98

January 1988

		Cubic Feet Per Month	Rate per 100 Cu.Ft. Inside City	Outside City
Step 1	First	2300	1.42	2.04
Step 2	Next	11700	.95	1.67
Step 3	Next	486000	.67	1.10
Step 4	Over	500000	.43	1.03

May 1989

		Cubic Feet Per Month	Rate per 100 Cu.Ft. Inside City	Outside City
Step 1	First	2300	1.49	2.14
Step 2	Next	11700	.99	1.75
Step 3	Next	486000	.70	1.16
Step 4	Over	500000	.45	1.08

January 1990

		Cubic Feet Per Month	Rate per 100 Cu.Ft. Inside City	Outside City
Step 1	First	2300	2.98	4.28
Step 2	Next	11700	1.98	3.50
Step 3	Next	486000	1.40	2.32
Step 4	Over	500000	.90	2.16

July 1990

		Cubic Feet Per Month	Rate per 100 Cu.Ft. Inside City	Outside City
Step 1	First	2300	2.09	3.00
Step 2	Next	11700	1.39	2.45
Step 3	Next	486000	.98	1.62
Step 4	Over	500000	.63	1.51

Normal

April 1, 1969	$1.40 per 1000 gallons
April 1, 1983	$1.60 per 1000 gallons
April 1, 1984	$1.75 per 1000 gallons
April 1, 1990	$1.85 per 1000 gallons

Champaign-Urbana

October 29, 1981

		Cubic Feet	Bimonthly Charge
Step 1	First	5000	.9684 per 1000 cu.ft.
Step 2	Next	20000	.7814 per 1000 cu.ft
Step 3	Next	225000	.4636 per 1000 cu.ft.
Step 4	Over	250000	.3894 per 1000 cu.ft.

Park Districts, Public Schools, and Libraries .411 per 100 cu.ft.

December 1, 1983

		Cubic Feet	Bimonthly Charge
Step 1	First	5000	1.1000 per 1000 cu.ft.
Step 2	Next	20000	.8900 per 1000 cu.ft
Step 3	Next	225000	.5300 per 1000 cu.ft.
Step 4	Over	250000	.4410 per 1000 cu.ft.

Park Districts, Public Schools, and Libraries .411 per 100 cu.ft.

March 10, 1987

		Cubic Feet	Bimonthly Charge
Step 1	First	5000	.9500 per 1000 cu.ft.
Step 2	Next	20000	.8900 per 1000 cu.ft
Step 3	Next	225000	.6200 per 1000 cu.ft.
Step 4	Over	250000	.5160 per 1000 cu.ft.

March 23, 1990

		Cubic Feet	Bimonthly Charge
Step 1	First	5000	1.0770 per 1000 cu.ft.
Step 2	Next	20000	.9910 per 1000 cu.ft
Step 3	Next	225000	.8060 per 1000 cu.ft.
Step 4	Over	250000	.6650 per 1000 cu.ft.