EVALUATING RURAL WATER SYSTEM PRICING STRATEGIES USING MATHEMATICAL PROGRAMMING

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Submitted to the Faculty of the Graduate College
of the Okahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
July, 1985

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ACKNOWLEDGEMENTS

I wish to thank my major professor, Dr. Dean F. Schreiner, who provided insights at all stages of my research. Without his help and guidance this research could not have been completed. I also wish to thank Dr. Daniel Badger, Dr. Glenn Knowles and Dr. Larkin Warner for agreeing to serve on my committee and providing their insights. Dr. James Osborn, Agricultural Economics Department Head, provided financial assistance which otherwise would not have made this project possible.

I also wish to thank the following: Dr. Francis Epplin and Dr. Joseph Schatzer who helped with the design of the mathematical programming model; James Alexander and Terry Kinzie who assisted with the regression models; Ginny Gann and her staff entered the data into the computer; and, Ann Govek who typed the rough and final drafts.

This research also would not have been possible wihtout the encouragement and support provided by my parents, Dr. and Mrs. Lynn E. Dellenbarger, Jr. This research is dedicated to my wife, Ann, for her support, ideas and patience. Without her I would not have achieved one of my goals.

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INTRODUCTION

Water is becoming an increasingly scarce commodity in the state of Oklahoma. The level of public furor created by the issue of transferring water from the eastern to the western half of the state is but one indication. Further evidence of the importance of water resources to the public was the appearance of State Question 581 on the general election ballot of August 28, 1984. State Question 581 would allow communities to borrow funds from a state created trust of twenty-five million dollars to aid in financing community and rural water systems. The legislation was passed and represents the first statewide community water bill to be approved in Oklahoma.

In 1983 the Oklahoma Rural Water Assocation had over 500 systems as members. The Association defines a rural water system as one that serves a population of less than 10,000 residents (Oklahoma Rural Water Association, 1973). Not all rural water systems serving a population of 10,000 or less are members of the Oklahoma Rural Water Association.

It is imperative that Oklahoma be wise in the use of public funds for the development of water projects. Economic information is vital to the best management of water resources. Management practices differ for the various systems, from recordkeeping practices to investment planning procedures, to pricing of water services. Without proper recordkeeping investment planning and pricing of water are determined with uncertainty. Correct pricing strategies allow systems to provide water to their customers while covering costs of operation and maintenance, water purchase, and additions to capacity. Since rural water systems have some characteristics similar to public monopolies, the objective is not to maximize profits but to maximize net benefits to members of the system. Failure to correctly price water frequently leads to inefficient resource use in building and managing water systems, extreme excesses or deficits in water system cash flows and inability of systems to adequately finance additions to capacity.

As shown in previous research, Oklahoma has seasonal differences in water demand (Dellenbarger, Myoung and Schreiner, 1983). Failure to take into consideration seasonal demands for water forces systems without sufficient reserves to implement rationing policies. This is observed in many parts of Oklahoma during the summer months. Low water pressure and rationing are often the result of failure to incorporate sufficient capacity or having insufficient water supplies available to meet peak demands.

Improved knowledge of household water demand and the cost of supplying water can be used to help design the optimal size and timing of investments in water system capacity. Properly designed rate structures can allow the system to use resources efficiently and maximize net benefits for the planning horizon.

Problem Statement

Growing rural demand for water and increased water scarcity creates a need for better planning and management of rural water services. Rural water systems are faced with rising user expectations, high fixed costs of investment and long amortization periods. As a result, examining and reappraising methods for planning rural water services is critical.

Two major problems exist in the planning of rural water services that can be addressed using economic theory and methods for measuring economic response. The first is determining optimum excess capacity under conditions of growth in water demand and economies of scale in rural water supply including water storage, treatment and distribution. Second, determining appropriate water pricing policies which utilizes resources efficiently and maximizes net benefits to planned water investments. Current economic planning and research procedures have not adequately addressed these two problems (Myoung, 1982).

Economic theory shows that marginal cost pricing results in the most efficient use of resources. However, rural water systems show significant economies of scale and, thus, marginal cost pricing results in total revenue less than total cost and losses to the system. The problem then becomes one of determining needed subsidies for systems to operate under conditions of marginal cost pricing or to determine a different pricing strategy to capture more of the consumers surplus and thus reduce negative cash flows and still price the marginal unit of water equal to its marginal cost.

Rural water systems in the capacity initiation or additive phase are faced with the problem of determining the least cost timing and size of capacity additions while being able to meet the demands of their customers. The common method of determining needed capacity is to estimate population growth and multiply it by average water usage. This method does not take into consideration the price elasticity of water for the consumer on an annual or seasonal basis. It also fails to take into consideration time dimensions of growth in demand and the economies of scale associated with operation and maintenance, water purchases, and capacity additions. The failure to incorporate either the elasticities of water at the consumer level or the marginal cost of supplying water generally leads to nonoptimal capacity decisions. The result is generally to add capacity sooner than expected and at a higher cost to the rural water system and, subsequently, the consumer.

Purpose and Objectives

The purpose of this research is to provide better economic information for planning and management of rural water systems in Oklahoma. The primary objective is to improve upon past community service planning models by incorporating both the consumer (residential) seasonal demand and the cost characteristics of rural water systems in the planning process and to utilize information from the planning models in pricing of water resources. Specific objectives are to:

1. Review the literature on pricing of water services under conditions similar to a public monopoly. Also, a review of techniques

for estimating seasonal household water demand, the price elasticity of water and the cost of supplying water to rural systems will be done.

2. Conduct a two phase survey for Oklahoma to obtain primary data on rural household water consumption and costs of rural water systems.

3. Estimate rural household water demand functions and cost functions for operation and maintenance of rural water systems using the survey data.

4. Develop a separable investment programming model that incorporates seasonal household water demand and annual cost characteristics of rural water systems.

5. Determine net social benefits, water system capacity, water demand, and financial results associated with marginal cost pricing for a hypothetical rural water system using the investment programming model.

6. Determine principles of water rate design based upon the review of literature, current pricing strategies of rural water systems and the results of the investment programming model.

7. Examine policy implications of the above results relative to rural water system management practices, pricing of rural water resources and use of public resources in community water resource development.

Plan of Presentation

The remainder of the text is divided into chapters. Chapter II provides a review of the economic aspects of water investment planning and under conditions of a public monopoly. It also contains a review of the techniques for estimating seasonal household water demand, price elasticity of water demand, cost estimation of water supply, benefit estimation from consumers and producers surplus and pricing of water to obtain financial feasibility.

Chapter III covers results of a rural water system survey on characteristics of systems and the estimation of cost functions for operations and maintenance, water purchases and investment.

Results of a rural water system household survey are contained in Chapter IV. Characteristics of households connected to rural water systems are provided and estimates of seasonal household water demand and seasonal price elasticities for water are presented.

An investment programming model considering seasonal demands and using separable programming is developed in Chapter V. The model formulates benefit functions from nonlinear seasonal household water demand equations; considers economies of scale associated with costs of operation and maintenance, water purchase and capacity investment; and maximizes net benefits under conditions of marginal cost pricing. The model determines optimal timing and size of investment, water demand on a seasonal basis and net benefits to the system. The optimal timing on size of initial capacity and additions to capacity are determined by the investment cost function.

Chapter VI covers the results of the investment programming model and the principles of water rate design. Seasonal and yearly water purchases are determined along with the monthly household water price and water demand. The financial situation is also presented on an annual basis for the given planning horizon. From the results of the model, review of literature and the actual water rates of respondents to the survey, principles of water rate design are determined.

Chapter VII presents a summary of the study, policy implications and conclusions.

CHAPTER II

THEORETICAL ASPECTS OF PUBLIC MONOPOLY WATER INVESTMENT PLANNING MODELS

Introduction

Farmer's Home Administration (FmHA) defines a rural water system as one which supplies water to 10,000 persons or less (Lawrence, 1980, p. 8). In 1982 those systems which are defined as rural by the FmHA supplied more than 95 percent of the nation's community systems but encompassed less than 25 percent of the population (Stevie, 1982, p. 13).

Grant and loan funding for up to 75 percent of an eligible project's cost is available from the FmHA (Ramanurthy, 1984). The median income level of a system is used in determining the amount of grant funds made available. Median family income is also used to determine the interest rate charged. If median family income is greater than $16,439 than the market rate of interest is used. An intermediate rate is used if median family income is between $9,900 and $16,439. A subsidized rate of five percent is used if median family income for the system is less than $9,900 (Ramanurthy, 1984).

Max Fletcher defines a public monopoly as one that is governed by a state or federal regulatory commission in the areas of:

1. Limiting their prices and profits to reasonable levels.
2. Providing adequate services in quantity and quality at the established prices even at peak times.
3. Getting advance approval for adding or dropping services.
4. Protecting the safety of the public period.

The public monopolist receives in return:

1. "Reasonable" prices and profits.
2. Complete or partial protection from competition.
3. The right to exercise eminent domain in acquiring property.

Fletcher further states that a public utility such as a rural water system has in addition to the above qualifications the following four:

1. Demand elasticities that differ among various groups of customers of the utility making it highly profitable for the company to discriminate in setting prices or rates.
2. Wide swings in the demand for the service provided.
3. Customers connected physically to the supplier.
4. A vital need by the customer for the output from the supplier.

Rural water systems fall under the qualifications listed for a public utility. Since the objective will be to maximize net public benefits rather than profits, the next four sections will cover benefit estimation and cost estimation for rural water systems. This will be followed by sections on consumer's and producer's surplus, public monopoly pricing strategies, investment planning models and distinctive aspects of this study.

Benefit Estimation

Supply Management or Requirements Approach

Henderson's series on managing small water systems states that before determining present and future water needs of a system, factors such as those listed below need to be estimated:

1. Present and future population.
2. Present annual use of water.
3. Rate of growth of water use.
4. Ratio of peak day, peak three hours and peak hour to average annual demand.

Henderson also includes factors of size of community, standard of living, location of community, quality of water, water pressure, metering and lawn sprinkling. Growth potential as measured by vacant land suitable for development, proximity of larger communities, potential new industry and low income mass housing should also be considered.

Hanke, however, points out a problem associated with this approach. The water industry employs what is often characterized as "supply management". Forecasts of water needs are determined by multiplying the projected population of the system by estimated average per capita use. By projecting water demand in this manner deficiencies in the supply system can be identified. Managers can then decide when and how much capital should be invested in new facilities. Supply management views water demand as a "requirement" that must be met and is outside the control of the system. Hence, no measurement of the benefits of water consumption are made.

The requirements approach does not take into consideration the consumer's demand function for water or the consumer's responsiveness to a change in price for water. Consumer demand and the consumers response to a change in price are covered in the next two sections.

Demand Theory Approach

Consumer demand for water is defined as the various quantities of water a consumer is willing and able to buy as the water rate (price) varies, ceteris paribus. The consuming unit is generally considered a household and, since water is not an inferior good, price and quantity will vary inversely and can be explained in terms of the substitution and income effects of a price change (Taylor, 1975). The two effects are shown in Figure 1.

Assume that the consumer has a choice of two goods, X and water. Further assume that initially the consumer is at point J where indifference curve I is tangent to the consumer budget line AB. The price of water is assumed to rise causing the budget line AB to rotate clockwise to AC. The consumer's new equilibrium occurs where budget constraint AC is tangent to indifference curve II, point K. As the price of water increases, water demanded decreases from W_2 to W_1. The increase in water price results in a lower real income for the consumer.

If consumers are compensated for the loss in real income so that they remain on the initial indifference curve I this would occur at point D. This new budget line is represented by LL with a quantity

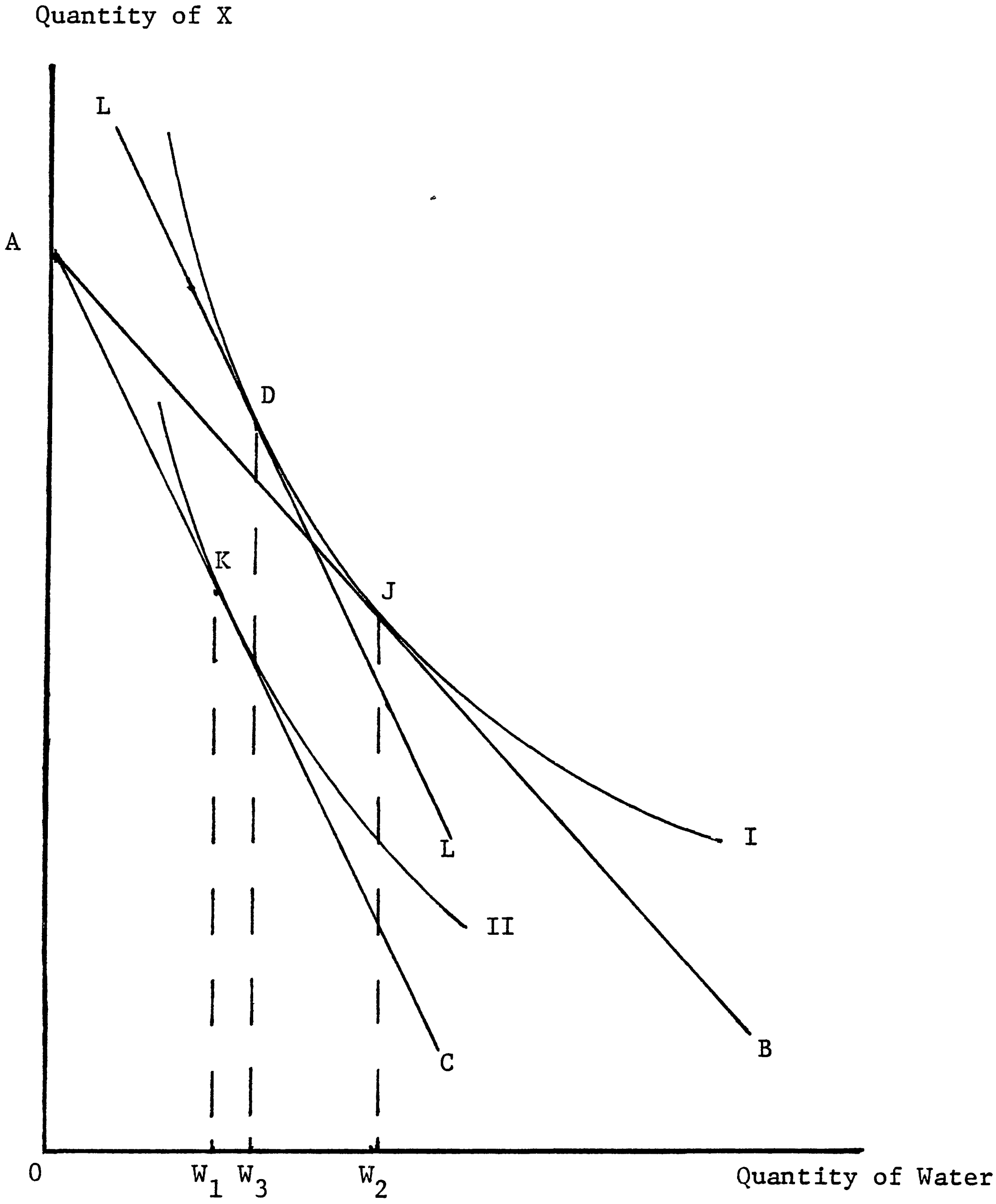


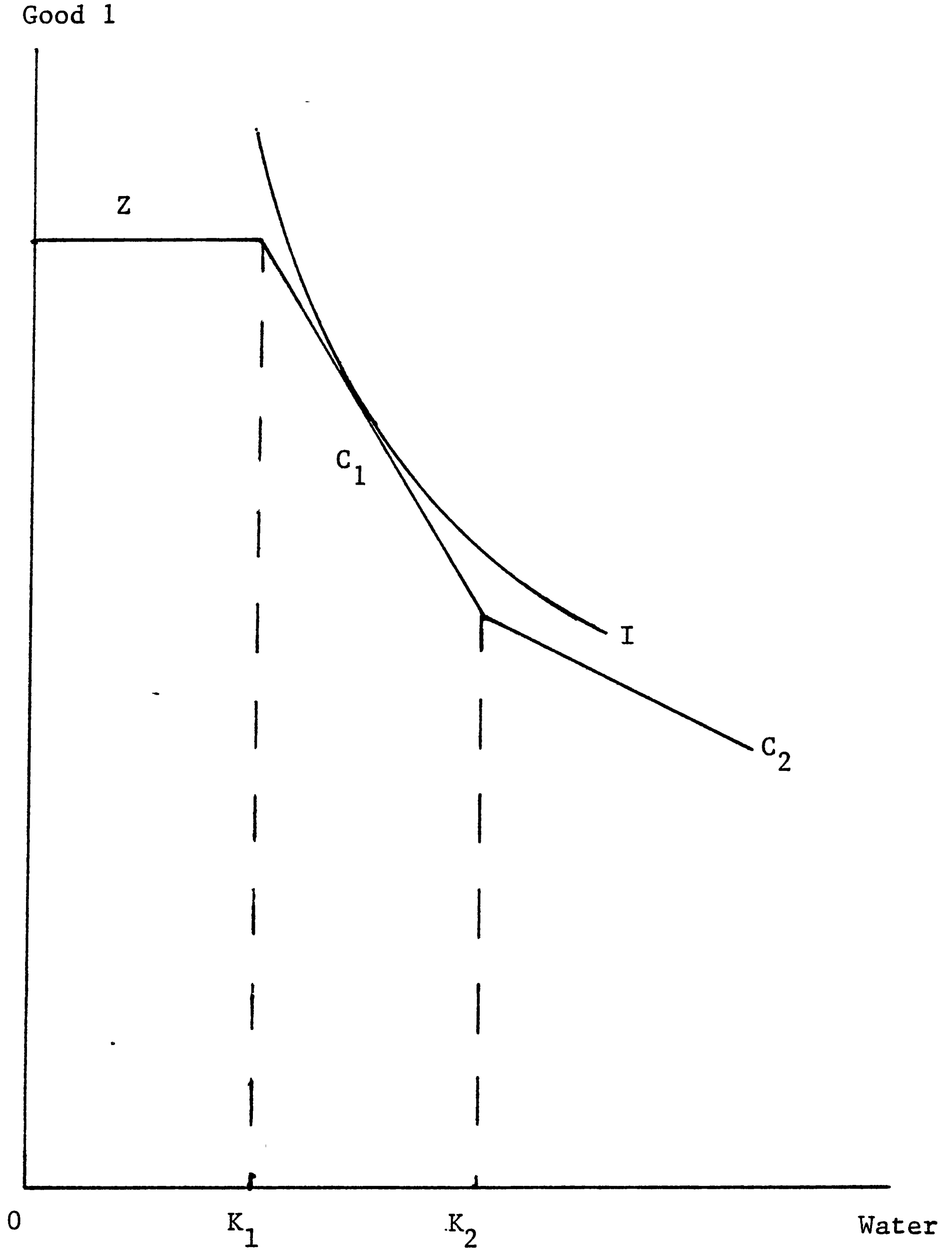
Figure 1. Substitution and Income Effect

demanded of W_3. The substitution effect in this case is represented by the change from W_2 to W_3. Gould and Ferguson (1980) define the substitution effect as the change in quantity demanded resulting from a change in price when the change is restricted to a movement along the original indifference curve, thus holding real income constant. The income effect of the price change is the difference between W_1 and W_3 and is defined as the change in quantity demanded resulting exclusively from a change in real income, all other prices and money income held constant (Gould and Ferguson, 1980).

The estimation of demand for water follows earlier work established for estimating the demand for electricity. Taylor brought forth problems associated with estimating demand for electricity since the consumer does not face a single price but a price schedule. Taylor defines the problem as follows.

Assume a consumer exists in a two good world with the consumer being able to purchase good Q_1 in unlimited quantities but at one price. Assume good Q_2, water, is subject to a two-part tariff with a decreasing block rate. The consumer's budget constraint with the decreasing block rate is shown in Figure 2 for our two good world of Q_1 and water. The consumer also has an indifference curve which is shown as I. By changing either a stage of the rate structure or income it will result in shifting the budget constraint with the consumer at a different equilibrium. A different bundle of goods will be selected due to the tangency with an alternative indifference curve.

Taylor presents three alternative scenarios using the rate structure listed below:



Source: Taylor, Lester D. "The Demand for Electricity: A Survey," The Bell Journal of Economics, Vol. 6, No. 1 (Spring 1975) pp. 74-110.

Figure 2. Multiple Price Tier Budget Constraint

1st K_1 gallons	Z (flat rate)
K_1 to K_2 gallons	C_1 per gallon
more than K_2 gallons	C_2 per gallon

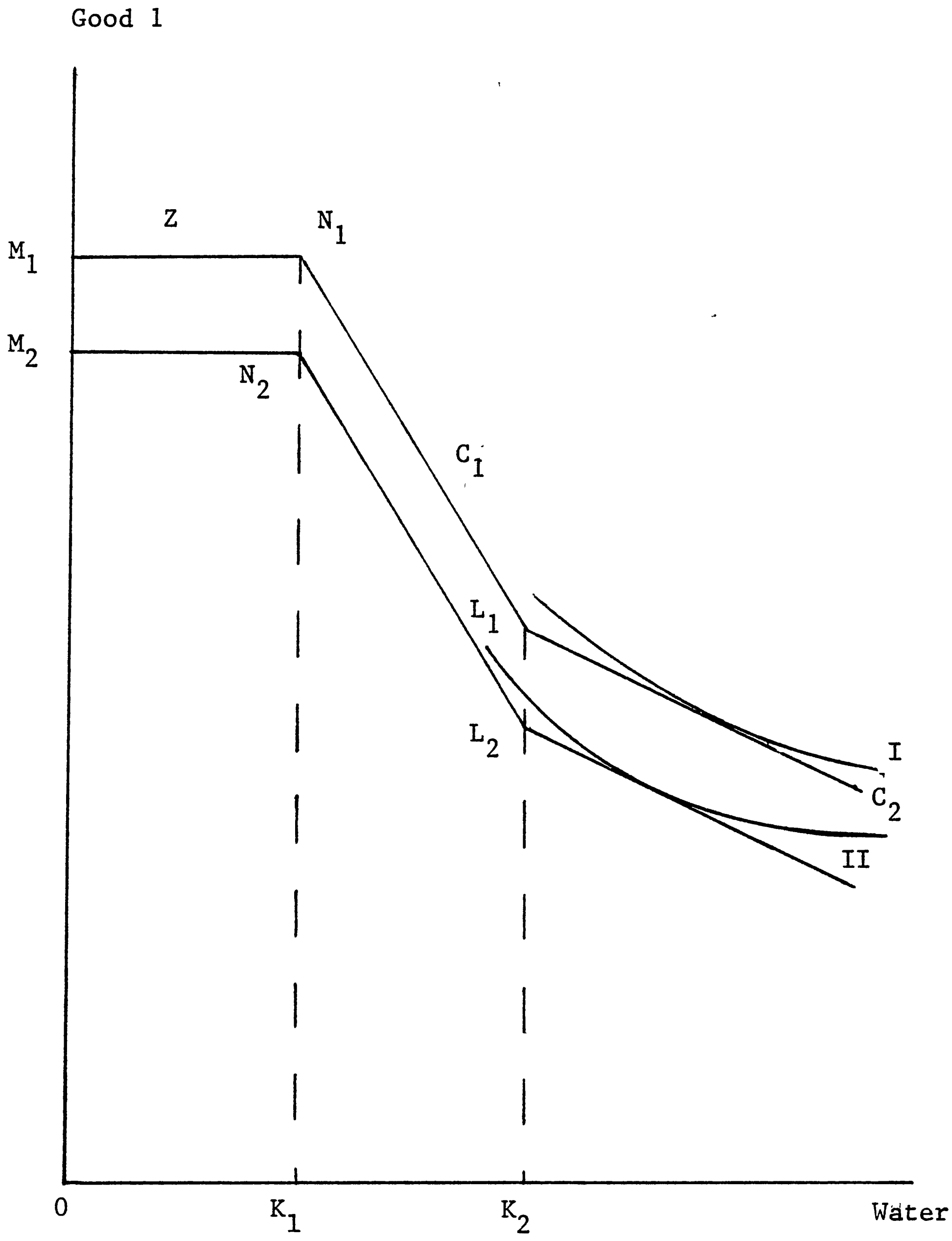
The scenarios are:

1. An increase in Z, C_1 and C_2 constant. Shown in Figure 3.
2. An increase in C_1, Z and C_2 constant. Shown in Figure 4.
3. An increase in C_2, Z and C_1 constant. Shown in Figure 5.

Figure 3 shows that an increase in Z results in a downward shift of the budget line from $M_1N_1L_1$ to $M_2N_2L_2$ with a reduction in water consumed. Figures 4 and 5 also show reductions in water consumed. However, the reductions in Figures 3 and 4 are due to the income effect entirely. This is due to the fact that the marginal price was not changed. But Figure 5 which shows a change in the marginal price results in both a substitution and income effect.

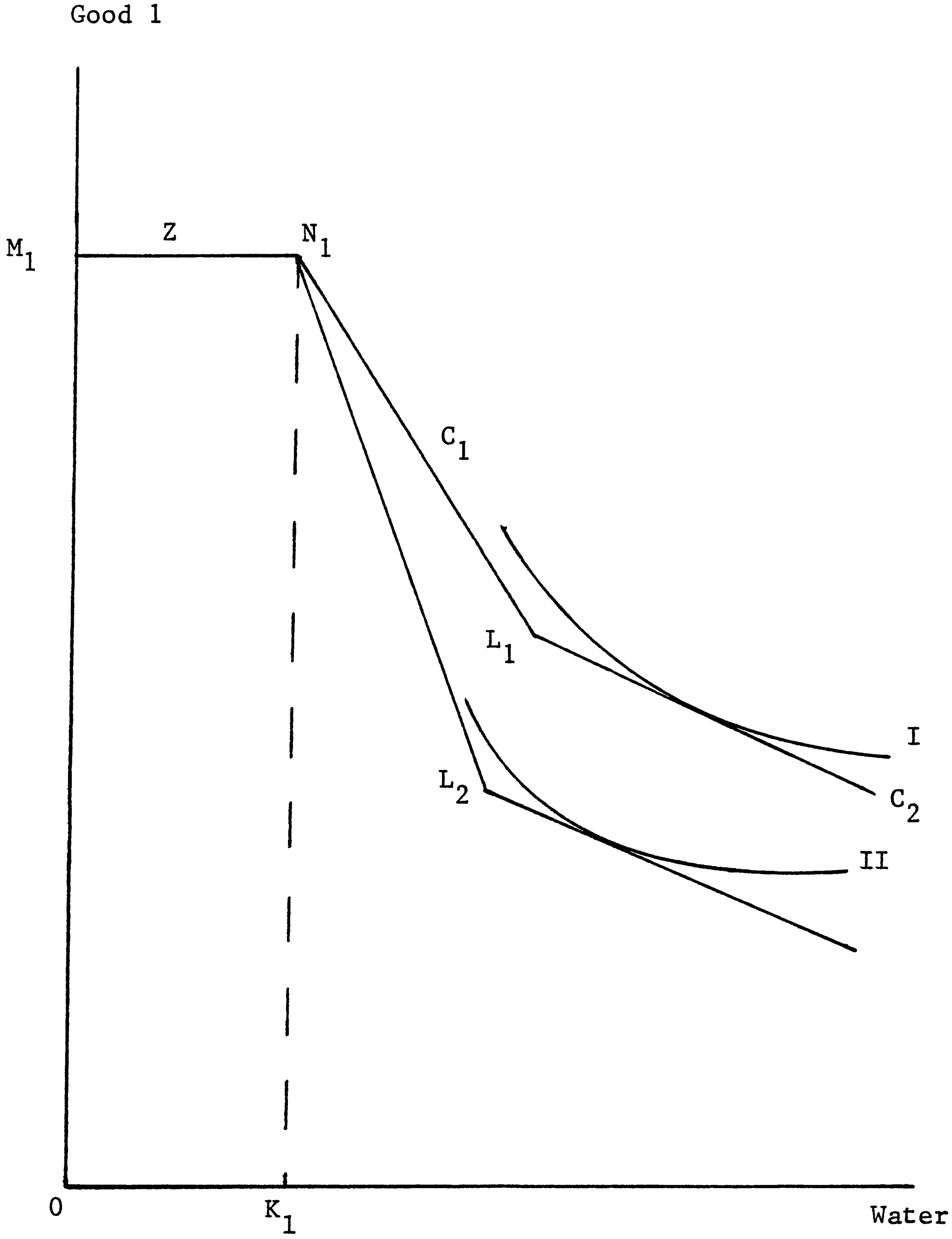
Taylor points out that average price used in the demand function along with income will identify the supply function. By using the rate schedule in the short run with the average price eliminates the problem.

Using both a marginal and an average price as predictors is the correct procedure in the estimation of a demand function. Marginal price is the last block consumed and average price refers to the average price of water consumed up to but not including the final rate. Using this approach the average price will estimate the income effect and the marginal price the substitution effect. Using average price as the only price variable in estimation tends to produce a larger estimate of the price elasticity of demand when decreasing block rates are used.



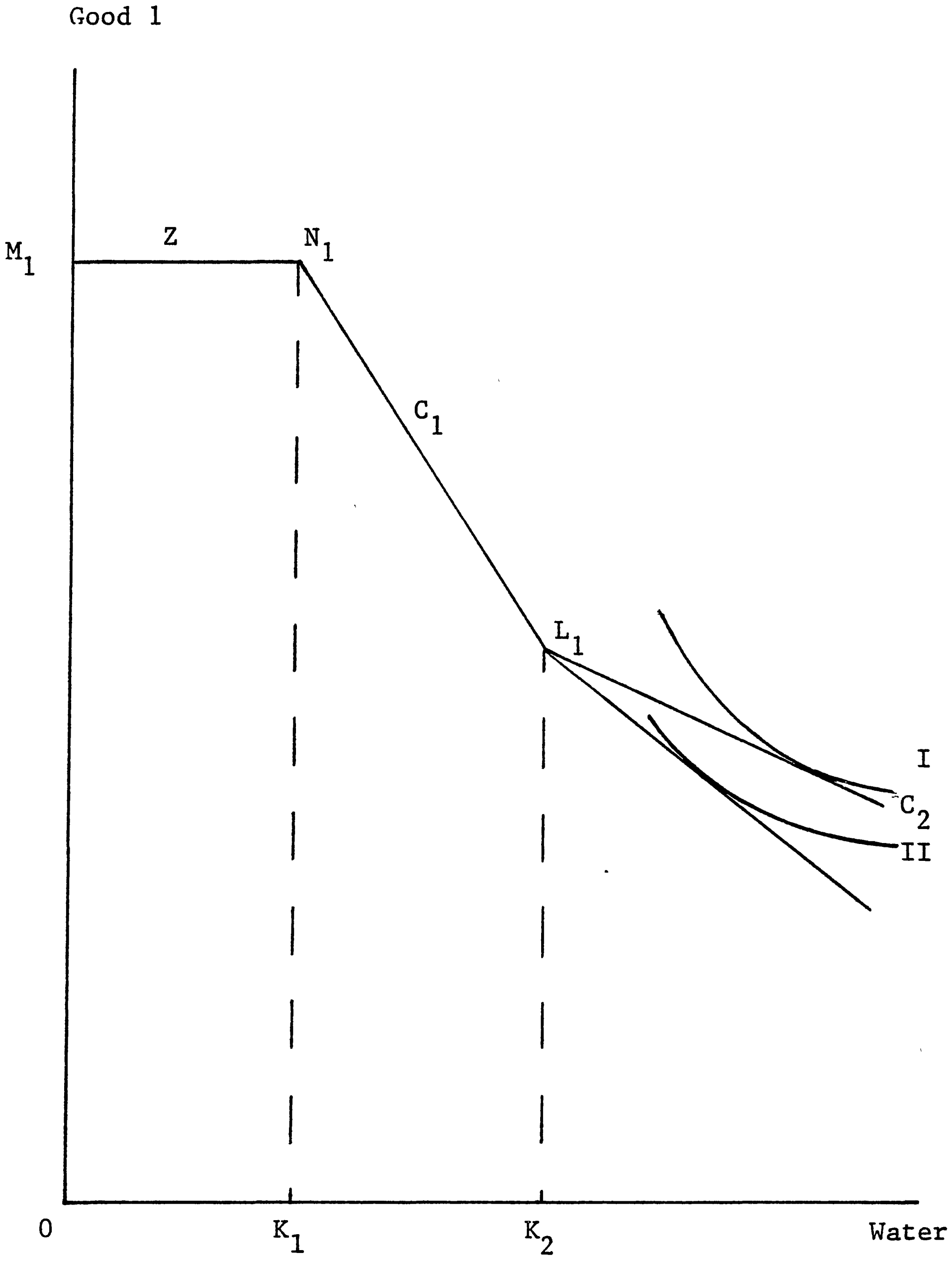
Source: Taylor, Lester D. "The Demand for Electricity: A Survey," The Bell Journal of Economics, Vol. 6, No. 1 (Spring 1975) pp. 74-110.

Figure 3. Change in Price of Initial Tier



Source: Taylor, Lester D. "The Demand for Electricity: A Survey," The Bell Journal of Economics, Vol. 6, No. 1 (Spring 1975) pp. 74-110.

Figure 4. Change in Intramarginal Price



Source: Taylor, Lester D. "The Demand for Electricity: A Survey," The Bell Journal of Economics, Vol. 6, No. 1 (Spring 1975) pp. 74-110.

Figure 5. Change in Marginal Price

Nordin states that the proper definition of the second price variable in the case of a decreasing block rate is the difference between the consumer's actual utility bill and what would have been paid if all units of the commodity were purchased at the marginal price. According to Nordin the difference variable can be described as the difference in consumer surplus occurring under uniform marginal pricing and the consumer surplus that is actually experienced by the typical consumer. This is shown in Figure 6.

Assume the household demand is represented by DD. The consumer faces the declining block rate schedule shown by the dashed lines. The marginal price is equal to point C where the rate structure intersects the demand function and Q_1 is demanded. Summing Areas 1 and 2 equals the consumer surplus for the household using marginal cost pricing. The actual consumer surplus that is experienced by the household using the decreasing block rate is Area 1. The difference variable is equal to Area 2.

Nordin's model is shown below:

$$Q = b_1 + b_2P + b_3D \qquad (2.1)$$

where

Q = monthly household water consumption

b_1 = intercept

P = marginal price facing the household

b_2 = coefficient of P

D = difference variable--actual water bill less what would have been paid if the water consumed was sold at the marginal price.

b_3 = coefficient of D

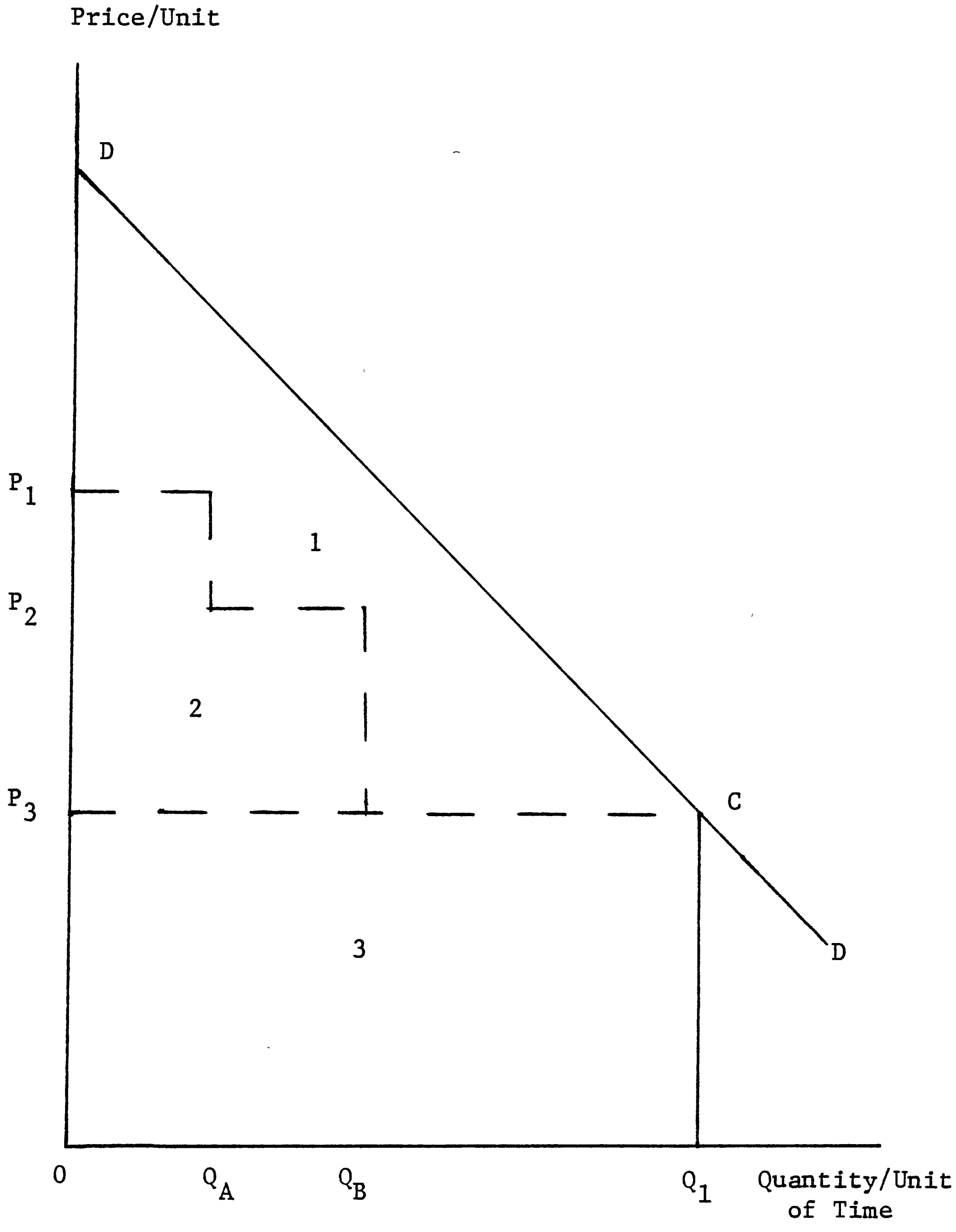


Figure 6. Substitution and Difference Variable

While the previous studies discuss demand estimation under a decreasing block rate, Billings and Agthe examined the situation in conditions of an increasing block rate. The introduction of the additional independent variable, household income, was stressed. The use of marginal price measures change in the price of the final unit of water purchased, the difference variable absorbs the income effects associated with the intramarginal rates, and the income variable absorbs all other changes of income which influence water uses.

Howe (1982) reexamined the above studies and added further insights into demand estimation. Agreement was reached on the functional form of the estimated demand function, but the expected sign of the coefficient for the difference variable was reexamined. Billings and Agthe proposed that the sign of the difference variable should be negative at all times. Howe (1982) showed that the sign of the difference variable would depend on whether the rate structure was an increasing or decreasing block rate. Howe's study showed that the value of the difference variable would be positive for decreasing block rates and negative for increasing block rates.

From the estimated demand function the price elasticity of demand can be determined. The price elasticity of demand measures the household's response to a change in price of the good.

Price Elasticity of Water Demand

The price elasticity of demand is defined as "the proportional change in the consumption of a good divided by the proportional change in the price of the good" (Leftwich, 1958). The price elasticity can be elastic, unitary or inelastic. Assume the price of a product falls by one percent. If the quantity demanded increases by more than one percent than the price elasticity is said to be elastic. For unitary price elasticity the one percent fall in price will be offset by a one percent increase in quantity demanded. A price elasticity that is inelastic occurs when the quantity demanded does not increase by one percent. The price elasticity of water is generally considered to be inelastic.

Much of the work on the price elasticity for water originated from methodologies developed from studies done on electricity. Hanke provides a summary of estimated price elasticities for water (Table I). The studies reviewed in the article were conducted prior to 1975 and therefore do not correctly estimate the price elasticity of water since either the marginal price or average price was used exclusively as the independent variable. As Nordin pointed out and later confirmed by Billings, Agthe and Howe, the independent variables for the price elasticity of water need to be marginal price, difference variable and income.

Howe (1982) shows that the price elasticity is derived with the difference variable. The difference variable $D = TR - Q \cdot P_e =$

$$[SC + \hat{Q} \cdot P_1 + (Q - \hat{Q})\ P_e] - Q\ P_e \qquad (2.2)$$

where all the variables pertain to a particular season. SC is equal to the service charge, TR equals total revenue and P_e is the equilibrium marginal price. Quantity $\hat{Q}$ at price P_1 is the first tier. The marginal tier is at price P_e for quantity $(Q - \hat{Q})$. The definition of the price elasticity then is equal to:

TABLE I

ESTIMATES OF ANNUAL PRICE ELASTICITY OF DEMAND ESTIMATES

Investigator	Price Elasticity	Comments
Bain, et. al (1966)	-1.092	41 water works systems in California: cross sectional
Clark & Goodard (1972)	-0.63	22 water works systems in Cincinnati, Ohio: cross sectional
Conley (1967)	-1.02 to -1.09	24 water works systems in southern California: cross sectional
DeRooy (1974)	-0.33 to -0.89	30 water works systems, industrial users, U.S.: cross sectional
Ellioti & Seagraves (1972)	-0.70	33 U.S. cities, industrial users: cross sectional
Ethridge (1970)	-0.40	5 poultry-dressing plants, U.S.: pooled time series, cross sectional
Fluck (1965)	-0.12 to -1.0	54 water works systems in western U.S.: cross sectional
Gallagher & Robinson (1977)	-0.24 to -0.89	14 households, residential in-house, Australia: cross sectional
Gardner & Schrick (1964)	-0.77	43 water works systems in Utah: cross sectional
Gottlieb (1963)	-0.86 to -1.24	Water works systems in Kansas: cross sectional
Grima (1970)	-0.93	91 water works systems; U.S.: cross sectional

TABLE I (Continued)

Investigator	Price Elasticity	Comments
Hanke (1970)	-0.59	Boulder, Colorado, residential in-house use: time series (1955-1968)
	-1.39	Boulder, Colordo, residential outdoor use: time series (1955-1968)
Harrington (1972)	-1.16 to -1.58	Industrial water use in England and Wales: cross sectional
Howe & Linaweaver (1967)	-0.703	10 water works systems in western U.S., residential outdoor use: cross sectional
	-1.57	11 water works systems in eastern U.S., residential outdoor use: cross sectional
	-0.231	21 water works systems in U.S. residential in house use: cross sectional
Metcalf (1926)	-0.65	29 water works systems, U.S.: cross sectional
Morgan (1973)	-0.25 to -0.45	Water supply systems in southern California, residential use: cross sectional
Rees (1969)	-0.956 to -6.71	Industrial water use in England: cross sectional
Renshaw (1958)	-0.45	36 water works systems, U.S.: cross sectional
Ridge (1972)	-0.30 to -0.60	Brewing and fluid milk plants, U.S.: cross sectional
Seidel & Bauman (1957)	-0.12 to -1.0	Water works systems, U.S.: cross sectional

TABLE I (Continued)

Investigator	Price Elasticity	Comments
Turnovsky (1969)	-0.05 to -0.4	19 water works systems in Massachusetts: cross sectional
Ware & North (1967)	-0.61 to -0.67	Water works systems in Georgia: cross sectional
Waog et. al (1963)	-0.01 to -0.72	Water works systems in Illinois: cross sectional
Wong (1972)	-0.02 to -0.28	Chicago, Illinois: time-series (1951-1961)
Young (1973)	-0.41 to -0.60	Tucson, Arizona: time-series (1946-1964)

Source: Hanke, Steve H. "A Method for Integrating Engineering and Economic Planning," Journal of American Water Works Association, (September 1978), pp. 487-491.

and

$$N_p = \left(\frac{\partial Q}{\partial P_e} + \frac{\partial Q}{\partial D} \cdot \frac{dD}{dP_e}\right) \cdot \frac{\overline{P}_e}{\overline{Q}} \qquad (2.3)$$

$$\frac{dD}{dP_e} = \frac{\partial TR}{\partial P_e} - Q = (Q-\hat{Q}) - Q = -\hat{Q} \qquad (2.4)$$

Howe reconstructed his earlier work with Linaweaver (1967) and found the price elasticity for water dropped significantly using the modified method of estimating price elasticity. Comparisons of the two studies are contained in Table II.

In the 1967 study, Howe and Linaweaver separated household demand from sprinkling demand. Howe's estimate for the 1967 price elasticity of water shown in Table II combined household and sprinkling allowing for the direct comparison of the 1967 study to the 1981 study.

By incorporating the price elasticity of demand into the pricing of water a household's quantity of water demanded can be examined subject to a change in price. The introduction showed that a rural water system's goal is not to maximize profits but to maximize net public benefits. Net benefits are derived from the household demand and cost functions. The next section covers costs of rural water systems in Oklahoma.

TABLE II

COMPARISON OF THE PRICE ELASTICITY FOR URBAN WATER DEMAND UNDER ALTERNATIVE MODELS

	1967 Study Without Difference Variable	1981 Study With Difference Variable
Winter Use	-0.23	-0.06
Summer Use - East	-0.860	-0.568
Summer Use - West	-0.519	-0.427

Source: Howe, Charles W. "The Impact of Price on Residential Water Demand: Some New Insights," Water Resources Research, Vol. 18, No. 4 (August 1982) pp. 713-716.

Cost Estimation

A pure monopoly is defined as a product having one seller in a market area with no good substitutes available. Most rural water systems can be characterized as close to pure monopoly. The public monopolist's objective is not to maximize profits but to maximize net benefits.

Water system development has largely depended on subsidies from federal, state and local government. Justification for the subsidy rests on the fact that water systems show significant economies of scale (Myoung, 1982). The limited market size faced by most rural water systems results in a failure to exhaust all economies of scale (Myoung, 1982).

Cost Categories

Costs are generally classified into categories of operation and maintenance, and investment. Costs can also be distinguished by user group: household, business, industrial and agricultural. Ide lists four steps in breaking down costs and classifying them to their user group:

1. Separation of the costs of investment and operation and maintenance into the following activities:
    a. production
    b. transmission
    c. distribution
2. Separation of activity costs into basic components such as maintenance of line, pumping costs, cost of alternative sources of water and size of line needed by various user groups.
3. Selecting a method for allocating cost components.
4. Allocating costs among users of the water service.

Dividing costs into two categories according to their user group is suggested by Banks (1979) in the following way:

1. Those related to facilities used by all customers such as water lines and treatment facilities.
2. Those related to facilities used exclusively by a particular user group. An example would be special water lines for an industrial unit.

Economies of Scale

Rural water systems operate to serve their customers both in the present and the future. Being dynamic in nature, rural water systems need to consider both the short-run and long-run costs associated with providing water. The short-run is defined as a period of time in which certain inputs cannot be increased or decreased. All inputs can be changed in the long-run.

Marginal cost (MC) is defined as the cost of producing or supplying an additional unit of output and can occur in the short-run (SMC) or the long-run (LMC). Average cost (AC) is the unit cost of producing or supplying Q units in either the short-run (SAC) or the long-run (LAC).

Figure 7 shows the relationships of the SAC, SMC, LAC and LMC. Three SAC functions are represented as SAC_1, SAC_2, and finally SAC_3. The average cost of producing a unit of output becomes less as the system is expanded from SAC_1 to SAC_3. The LAC curve is derived from the SAC curves. It represents the least unit cost of any output given various plant size. It is frequently called an envelope curve.

LMC intersects LAC at its minimum point. The LMC represents the minimum amount by which cost is increased when output is expanded and the maximum amount that can be saved when output is reduced (Leftwich, 1958).

Cost functions estimated for rural water systems in Oklahoma show convexity. Average and marginal cost functions were estimated for operation and maintenance and water purchases. The costs used in

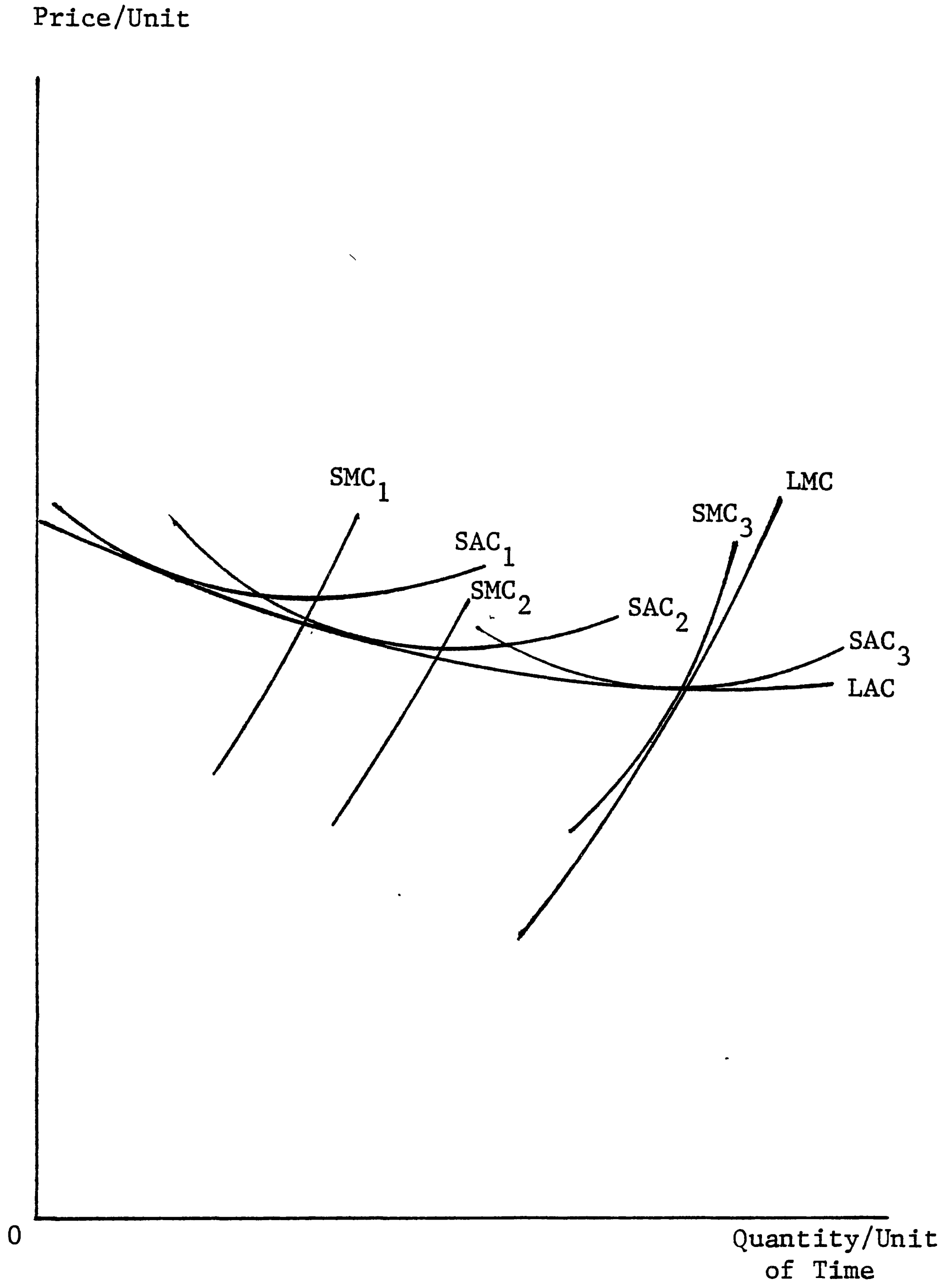


Figure 7. Cost Relationships for Rural Water Systems

obtaining the functions do not include the interest charges for financing expansions. Assume two water systems, A and B, which are planning to expand water storage facilities by the same amount. Assume further that the bids received for construction of the storage facility are the same. It is assumed System A has a better credit rating and a higher median income than System B. Assume System A can fund the expansion internally, whereas System B has to enter the money market.

The cost of the actual physical construction is the same for both systems. The difference is in the median income level, financial situation of the water system and the system's credit rating. For this reason the actual cost of construction is separated from the money market costs. One objective of this study is to determine pricing strategies which will allow rural water systems to finance projects internally without having to enter the money markets. For that reason the cost of interest will not be considered.

Replacement Cost

A question arises concerning the replacement cost of water. Those systems which purchase their water from another source are generally charged a price for the water. However, systems which obtain their water from groundwater sources generally do not include a cost for water itself. Only the cost of pumping water from the ground is considered. This approach computes an indirect cost for water as reflected through its pumping cost, but does not compute a cost associated with water replacement.

Oklahoma's groundwater law states that if an entity owns the surface rights, then the groundwater beneath it is also part of that property (Oklahoma Water Resources Board). This holds only if one user does not preclude a neighboring landowner from using the same water source. The current law does not put a price on water scarcity. Figure 8 shows the existing problem.

Assume two groundwater sources of supply for a rural water system with perfect recharge, A and B. Further assume that both are at the same depth and of the same quality. If the costs of pumping were the same for both sources then the value of water from source B would be equal to the value of source A due to the perfect recharge assumption. There would be no value put on the water since it is assumed infinite. A water system could choose either one of the sources.

If source A had a high water quality, while source B had a low water quality, then source A would be used since source B would have to be treated to make it comparable to source A.

Assume now that only source A exists and that the recharge is equal to the demand for water. This again would be a situation where water supply can be considered nonexhaustable. A problem arises when the recharge does not equal the quantity of water demanded. Seasonal weather conditions may influence the quantity demanded. Once water becomes less than infinite in availability it takes on a scarcity value. The problem then is determining the time value of water. What are the implications of using water now versus the future? Will it be used for household, agricultural, industrial or municipal purposes and what will be the ordering in preference for use?

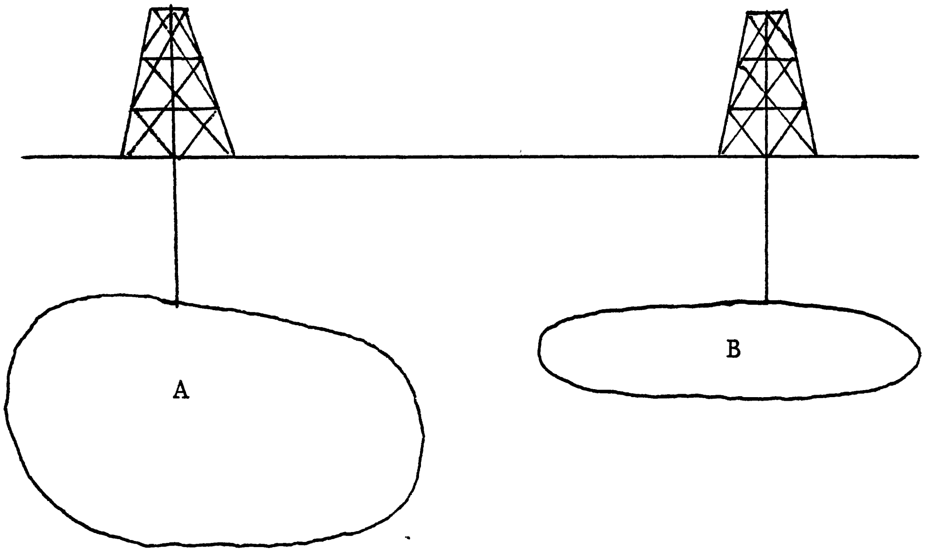
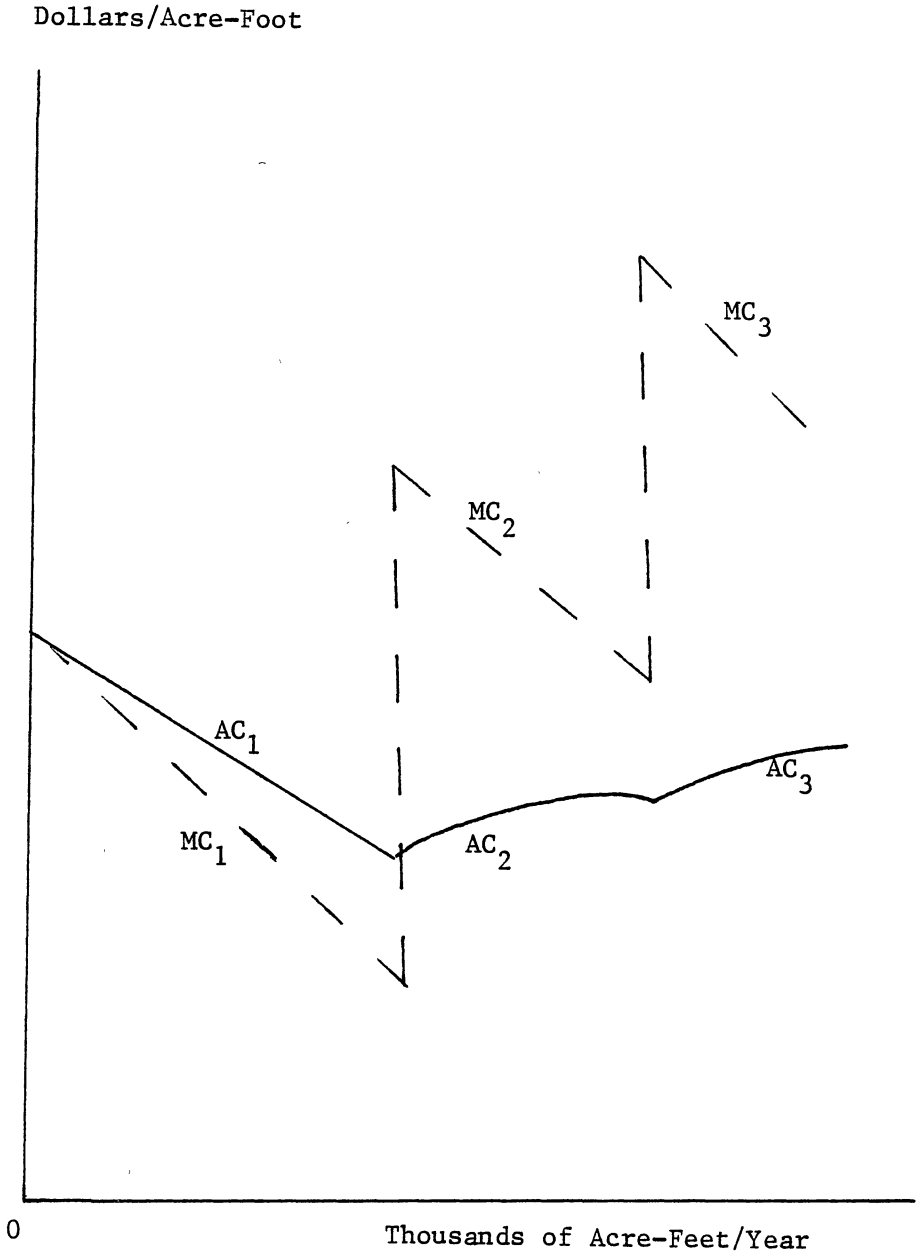


Figure 8. Alternative Water Supplies

The "Tragedy of the Commons" discusses a similar situation with a village green being the example. Since there is no cost to the use of the village green it becomes exploited and its value drops. Rural water systems are in a similar situation. There is one available source of water used for household, industrial, agricultural and municipal purposes. As the water supply drops or becomes nonexistent, the need arises to find another source. Since communities are not mobile, available water supplies become increasingly important. With limited water supplies and growth in water demand, water takes on a value. This is shown in Figure 9.

Assume that initially a rural water system has one source of water. As water is extracted in greater amounts economies of size are obtained (Martin, 1984). Marginal cost (MC_1) will be less than average cost (AC_1). But as original sources of water are exhausted the costs of extracting more water increase since alternative supplies of water will be used. This is shown by MC_2 and AC_2. Initially MC was less than AC, but as additional sources of supply are brought into use MC becomes greater than AC. Depending on the costs for operation and maintenance and investment with the MC greater than AC for water supply, profits could be obtained for the water system using marginal cost pricing.

By incorporating a system's demand and costs net social benefits can be derived. Net benefits here are defined equal to the summation of consumer surplus and producer surplus.



Source: Martin, William E., Helen M. Ingran, Nancy K. Laney and Adrian H. Griffen. Saving Water in a Desert City: Washington, D.C.: Resources for the Future, Inc., 1984.

Figure 9. Marginal Cost Using Alternative Water Supplies

Consumer's and Producer's Surplus

The concept of consumer's surplus originated in 1844 by Jules Dupwit. Alfred Marshall defined consumer's surplus as:

> the excess of the price which he would be willing to pay rather than go without the things over that which he actually does pay is the economic measure of the surplus satisfaction (p. 124).

Since the time of Marshall's definition controversy has centered not only on how consumer surplus is to be measured, but also if it actually exists. There is general agreement that it exists but not uniquely.

Whereas Marshall's definition of consumer surplus can be measured from market information, other measures of welfare change cannot. Two alternative measures of welfare change are compensating variation, and equivalent variation (Mishan, 1969). Compensating variation is defined as the amount of income necessary to restore a consumer to their initial indifference curve. Equivalent variation is the amount of income the consumer would be willing to forego, rather than lose the opportunity to consume the good.

The problem found in handling these two measures is that utility must be measurable. Research conducted by Willig shows that the measured difference between consumer surplus and compensating variation and equivalent variation is minimal and in certain instances nonexistent.

The measured differences hinge upon the income elasticity of demand for the good in question. As the income elasticity of demand decreases, the discrepancy of compensating variation and equivalent variation in relation to the ordinary consumer surplus diminishes. Willig states that this discrepancy in difference is probably smaller than the errors arrived from using econometric methods to derive the parameter of the demand function.

As Marshall defined consumer surplus, it is equal to the area below the demand function and above the equilibrium price. Producer surplus is the area above the MC curve and below the equilibrium price. Figure 10 displays a linear demand and nonlinear MC function. In this example MC is rising. The quantity demanded is Q_1 at a price of P_1. The triangle P_1 P_2 X is the consumer surplus. Producer surplus is equal to the area above the MC curve and below the equilibrium price, area P_1 P_3 X. Adding the consumer surplus to the producer surplus equals net social benefits. The objective of welfare economics is to maximize net social benefits.

Rural water systems, however, generally operate in the decreasing portion of the MC function. Figure 11 displays a linear demand and decreasing MC function. Consumer surplus is equal to the triangle P_1 P_2 X. But producer surplus does not exist since the MC function lies above the equilibrium price. Under decreasing marginal cost the objective of maximizing net benefits is equivalent to maximizing consumer surplus since producer surplus does not exist.

Public Monopoly Pricing Strategies

Conventional Pricing Strategies

From the 1860's until the turn of the century, a flat rate charge was generally used for industrial and residential water users. Flat

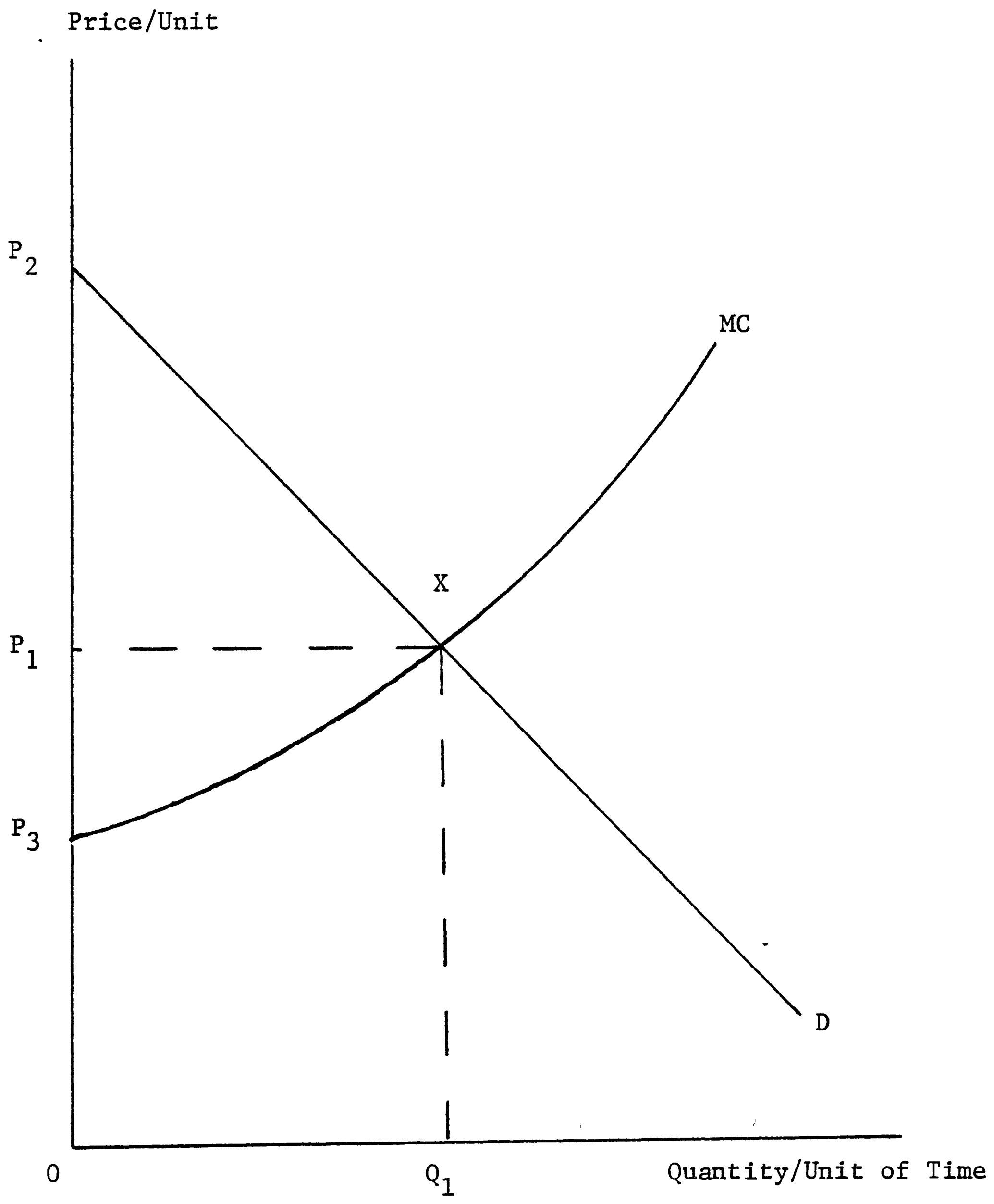


Figure 10. Consumer and Producer Surplus

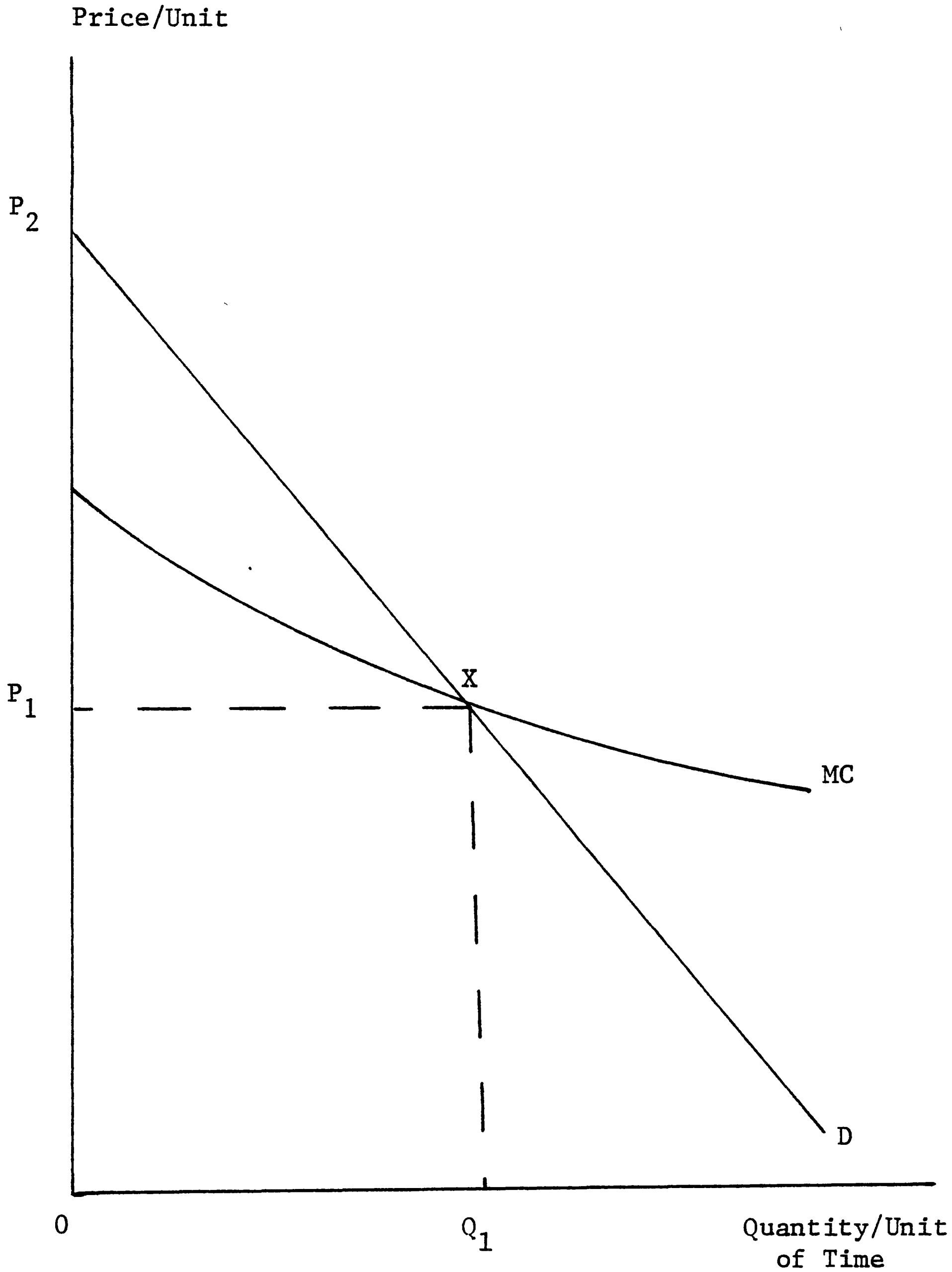


Figure 11. Net Social Benefits Under Decreasing Marginal Cost

rates were applied less often after water meters were introduced. Large numbers of industrial users were first metered between 1900-1910. Residential metering first occurred between 1920-1935. Metering of water has since become associated with the declining block rate structure (Ide, 1980).

Ide stressed when designing a rate structure it must be fair to all customers and to the utility. The design of a satisfactory rate structure falls into three categories: (1) study of revenue requirements; (2) allocation of costs to various classes of users; and (3) the actual design of the rate structure.

Lippiat and Weber characterize rate structure design by five types: (1) fixed charge per period; (2) uniform rate per unit; (3) varying rate per unit; (4) peak load pricing--seasonal; and (5) mixed. This list of rate structures fails to consider marginal cost pricing.

Fixed charge per period is referred to as a flat rate and is often associated with nonmetered water. A strong criticism of this type of rate structure is that it promotes water consumption. Whether a household consumes a thousand, ten thousand, or one hundred thousand gallons of water per month it is charged only one price.

Decreasing and increasing block rates are examples of varying rates per unit depending on quantity consumed. With decreasing block rate structures, the subsequent rate per unit decreases as consumption increases. Several problems exist with this approach. First it promotes water consumption since per unit costs decrease as consumption increases. Second, senior citizens or those on fixed incomes such as social security or welfare recipients actually support large water users who consume a greater than average amount of water. This occurs both during the winter and summer demand periods. Systems that are currently facing capacity constraints with limited funding for additions to capacity should not favor a decreasing block rate since it would result in future water shortages and decreases in water pressure.

Increasing block rates are ones in which the block rate structure increases as consumption increases. It also has several negative consequences. In a declining cost system it further reduces total revenue by reducing consumption and increases the cost per unit due to the cost of excess capacity. The positive aspect is that it promotes overall water conservation.

Peak load pricing increases the cost per unit when using water during high water demand periods but reduces cost when not in peak demand. An example of this type of pricing would be a surcharge added to a household's water bill during a given time of the day such as the early evening. Objectives of peak-load pricing is to reduce water use during heavy demand periods. The result is generally one of reduced demand on the consumers part and a prolonged use of the system's current capacity.

Seasonal pricing strategies are a form of peak load pricing with the summer months being the peak load period. Rate structures are differentiated for the winter and summer seasons with the objective to reduce water demand during the summer months. Prerequisites for effective seasonal and peak load pricing strategies are (Renshaw, 1982):

1. Substantial variation in demand between peak and off peak periods.

2. Installed capacity requirements must be determined primarily by the peak demands of the system.

3. The water utility must have peak demands that consistently occur during the same season or time of the day.

4. The utility must be able to estimate the differences in cost between meeting peak and off-peak demands.

Mixed rates are the most common rate structures currently being used by water systems. A common mixed rate incorporates a fixed charge for a first level of consumption and then incorporates a decreasing block rate for succeeding levels of consumption. Another common rate structure first incorporates a fixed rate, followed by a decreasing block rate to a certain consumption level and then an increasing block rate.

A water pricing innovation is the implementation of life-line rates. Life-line rates assist limited income households to obtain affordable water services. The low cost however encourages water usage of participating households. Renshaw suggested in place of a life-line rate that a system should charge a uniform price and give tax reductions or lump sum credits to low income families.

Marginal Cost Pricing

The problem with the above pricing strategies is that mixed signals are given to the consumer. Marginal cost pricing avoids this problem. Two justifications for the use of marginal cost pricing are: (1) economic efficiency for resource use by the utility; and, (2) the consumer is receiving the correct price signal for the commodity. Households would use water efficiently since the value placed on an additional unit of water is equal to the cost of supplying an additional unit of water. The pure monopolist's demand, MR and MC curves are presented in Figure 12.

A price would be set to allow the regulated monopolist a profit at a predetermined level. This scenario results in a profit for any predetermined price higher than P_3 at Q_5 and maximizes profit at P_2. The goal of a public monopolist is not profit maximization but to maximize net benefits which is obtained when the marginal cost is equal to the marginal benefit of the last unit of water consumed. Marginal cost pricing allows for the optimal use of resources and provides the correct pricing signal to the consumer. But under a decreasing unit costs as portrayed in Figure 12, and representative of most rural water systems, marginal cost pricing will result in a loss. Marginal cost pricing results in a price of P_6 and Q_6, the quantity demanded.

Figure 13 shows a household demand function in graph A and the water system aggregate demand and MC curve in graph B. The water system equates aggregate demand with marginal cost and supplies that quantity of output. The optimal output for the rural water system is Q_e at a price of P_e. By equating price P_e to the household demand in graph A, the household equilibrium can be determined. The household quantity Q_c is consumed at a price of P_e. For this situation the rural water system operates at a loss, but net public benefits are maximized. However, a pricing strategy can now be

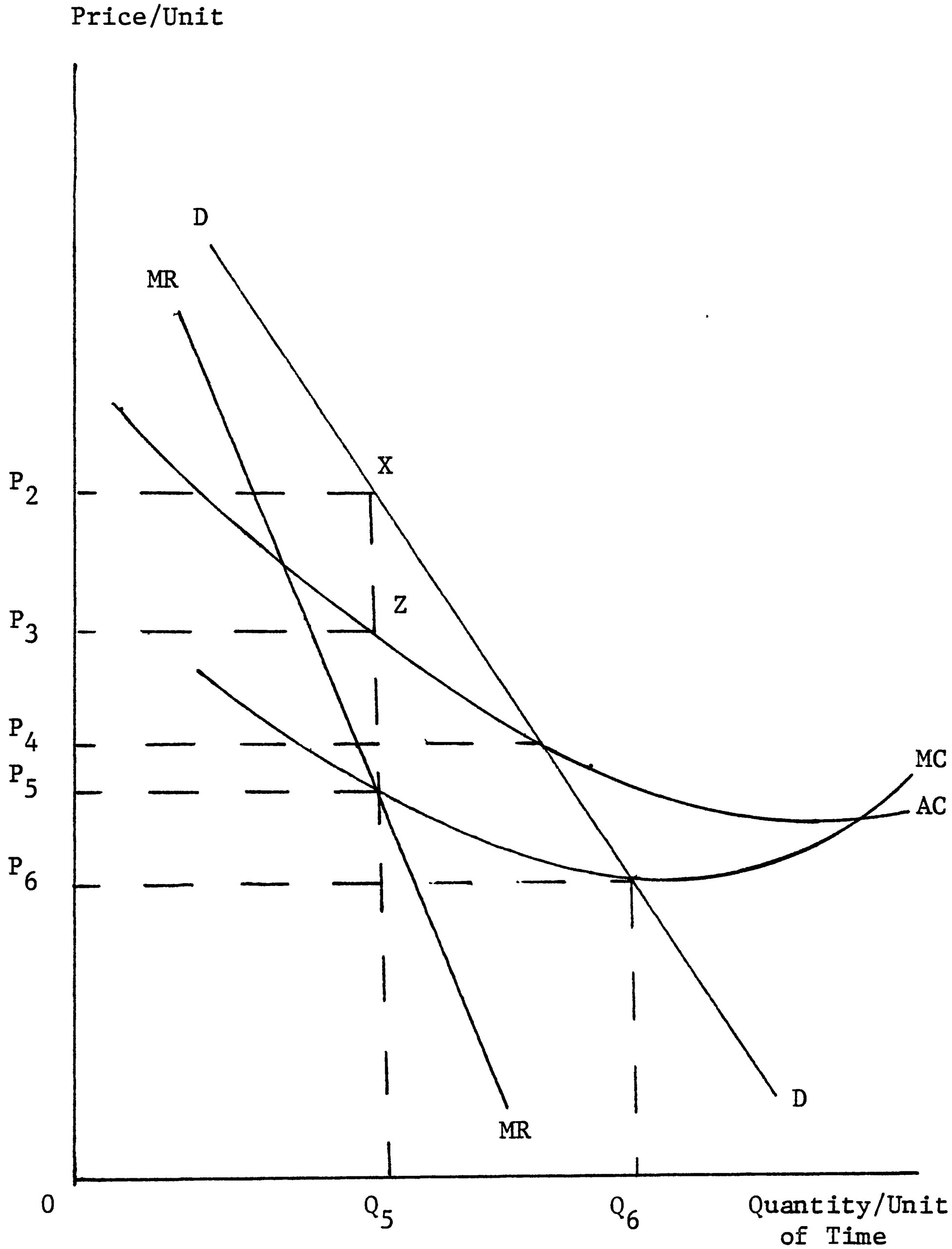
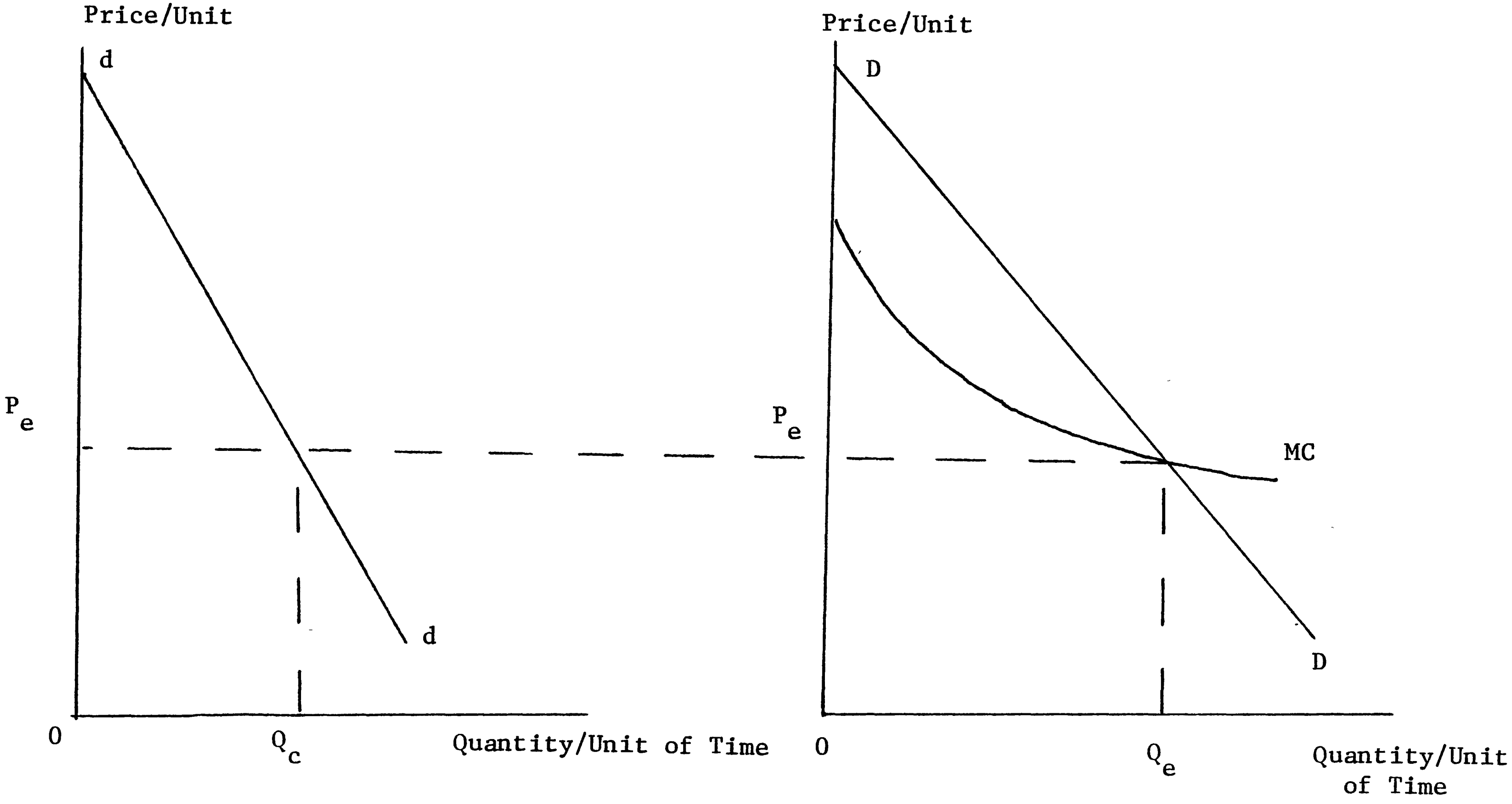


Figure 12. Monopoly Price and Quantity



Graph A Household

Graph B Industry

Figure 13. Industry and Household Equilibrium

determined using the marginal cost price of P_e as the final block in a multiple tier rate structure. Graph A is enlarged in Figure 14 to provide an example.

Equilibrium price is still P_e and the quantity demanded is Q_c. A multiple tier rate structure is presented as the dashed lines. For the first Q_1 thousand gallons of water, price P_1 is charged. The second stage of the rate structure has a price of P_2 for $Q_2 - Q_1$ thousand gallons of water. The marginal cost or third tier in the rate structure is the marginal price, P_e. The rate structure designed for a water system will be governed by equating the aggregate demand to the marginal cost, the financial status of the rural water system and the goal of maximizing net public benefits. A decreasing block rate is shown in Figure 14, but an increasing block rate could also have been displayed. Using an increasing block rate would generally result in increased net public benefits and a profit for the rural water system. The next section discusses the investment planning models using marginal cost pricing.

Investment Planning Models

Current Models

Engineering studies frequently operate using "supply management" criteria to meet projected water demand. Future demand is determined by multiplying average per capita usage by the projected population. This method fails to take into consideration economies of scale, household demand and the price elasticity of demand.

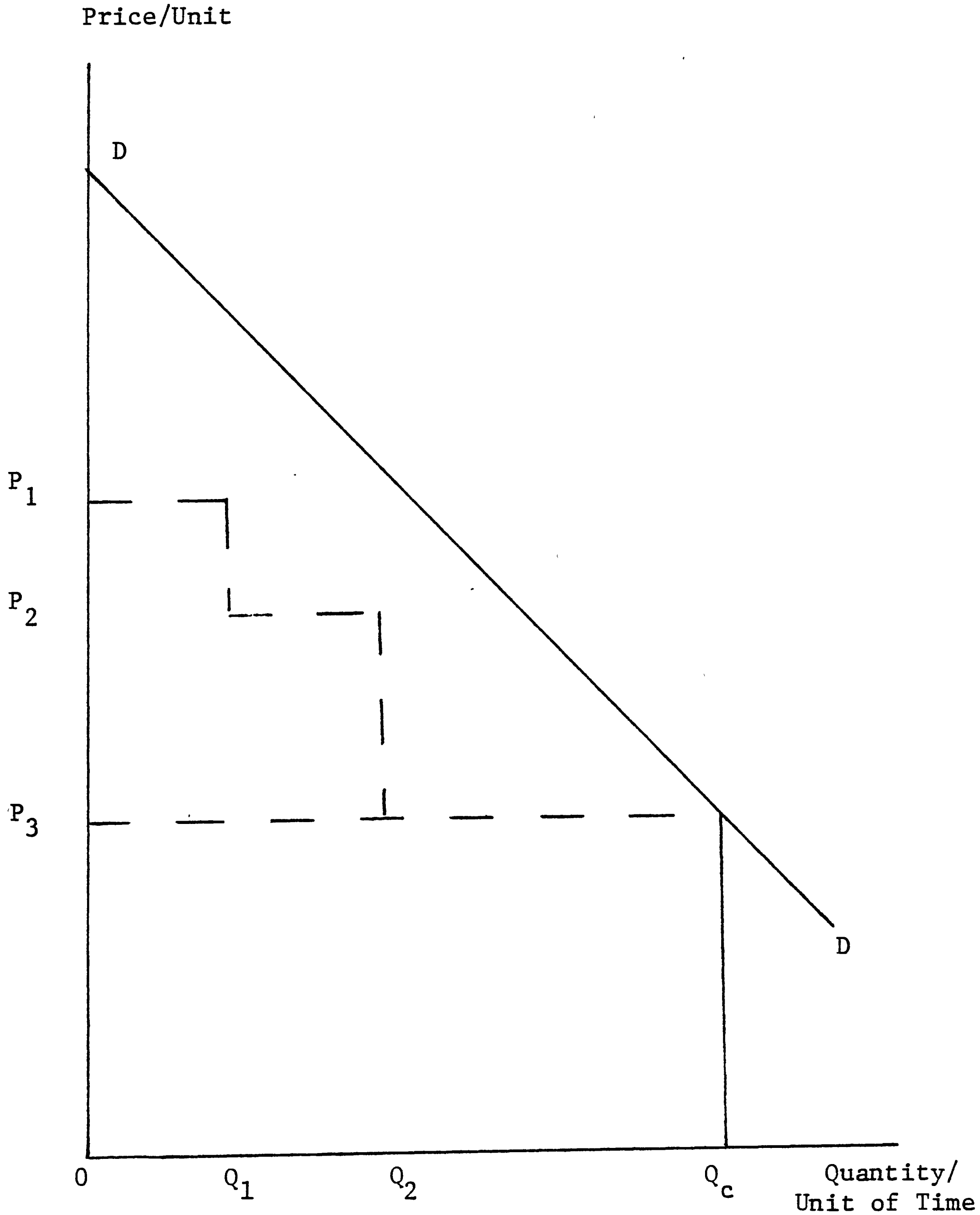


Figure 14. Household Water Rate Design

Two recent economic studies are critiqued. Moore and Yeh developed a multiperiod dynamic programming model to determine optimal capacity expansion for reservoir construction. The programming model is mixed integer and uses price sensitive demand functions that vary with time. The objective is to maximize net benefits.

Myoung also developed a multiperiod linear programming model to determine optimal capacity, water supply and price for rural water systems. The model is mixed integer, uses price sensitive demand functions that vary with time, and maximizes net social benefits.

Differences in these two studies arise in their ease of application. Dynamic programming collapses if the size of the model gets large. Current modifications have enlarged Myoung's study to approximately seven hundred columns for a 20-year planning period which is not in the size range for a dynamic programming model. Dynamic programming needs to be totally remodeled for each application, whereas Myoung's model can be incorporated for other applications with minimal change. Myoung's is currently being modified for rural extension work to aide rural water systems. Due to its greater application to other projects, Myoung's model will be studied and modified in the remainder of this thesis.

Myoung's model maximizes net public benefits. The model operates from a segmented demand function using separable programming as explained by Duloy and Norton. An example is shown in Figure 15. Aggregate demand is represented by D in Figure 15 and by the following inverse demand equation:

$$P = a + bQ \qquad (2.5)$$

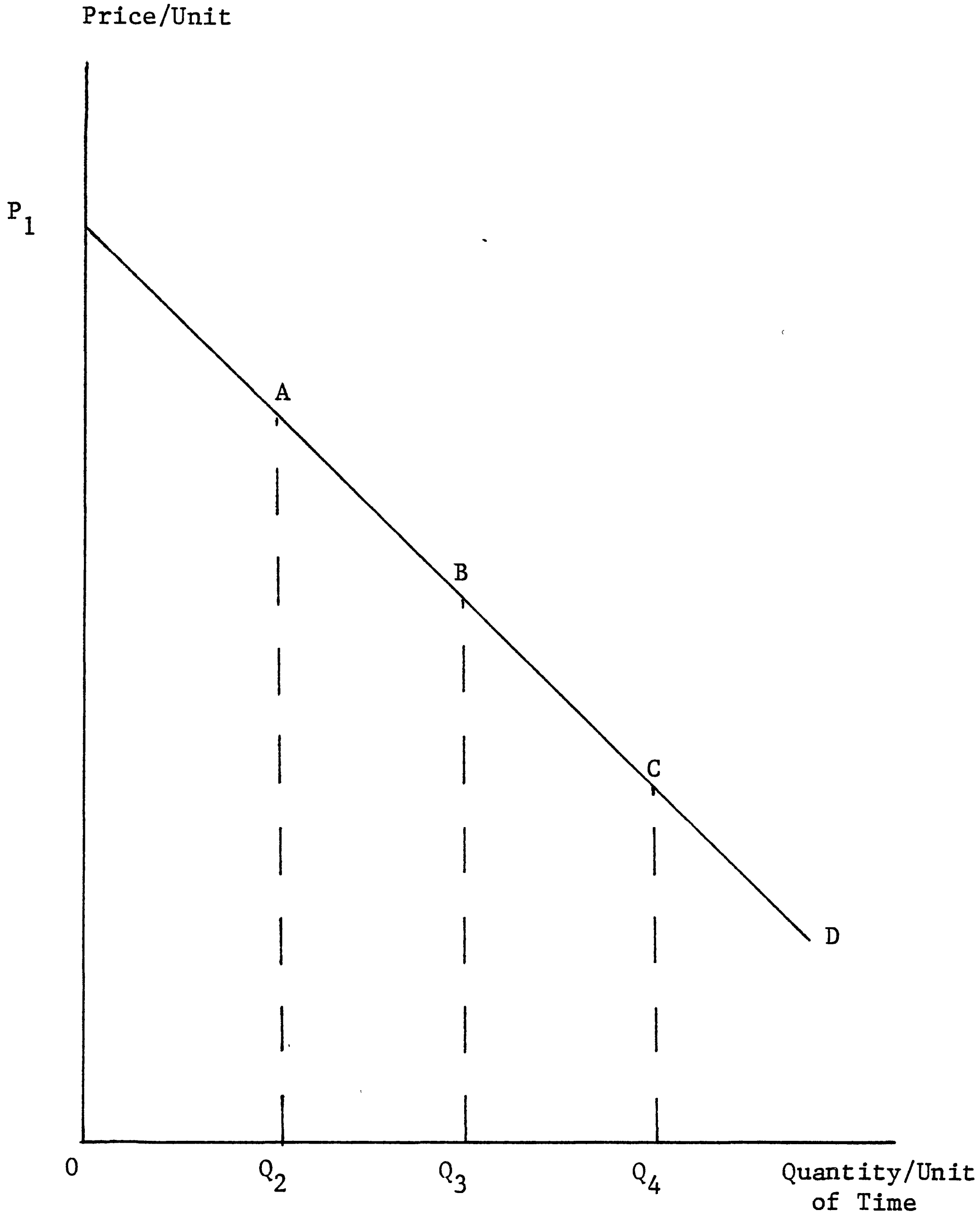


Figure 15. Separable Demand

where

P = price per thousand gallons

a = intercept

b = slope of the demand function

Q = quantity demanded in thousands of gallons

Integrating Equation 1 by Q results in the area under the demand function at various quantities of water demanded. The area under the aggregate demand function is expressed in dollars and discounted to the base period. Figure 15 segments the aggregate demand function into three parts. Using quantity Q_2, the area under the aggregate demand function is $P_1\ AQ_2\ 0$. If Q_3 is used as the quantity demanded the area is $P_1\ BQ_3\ 0$. For quantity Q_4 the real or total revenue would be $P_1\ CQ_4\ 0$.

Myoung's model determines the optimal quantity demanded by interacting the aggregate demand and costs internally. Operation and maintenance and investment cost functions are estimated. Operation and maintenance is used as a variable cost depending on the quantity supplied to the households. Investment cost is divided into two segments: fixed and variable. The fixed portion occurs each time investment occurs with the variable investment cost subject to the capacity addition. Investment costs occur only in the periods of capacity addition. Figure 16 shows the combined interaction of the operation and maintenance cost with the investment cost.

Initially a water system incurs investment costs to operate the system. This is represented by point A. As the system supplies greater water quantities, marginal cost decreases and follows MC_1 down to quantity Q_1 at point B. Economies of scale are shown by the

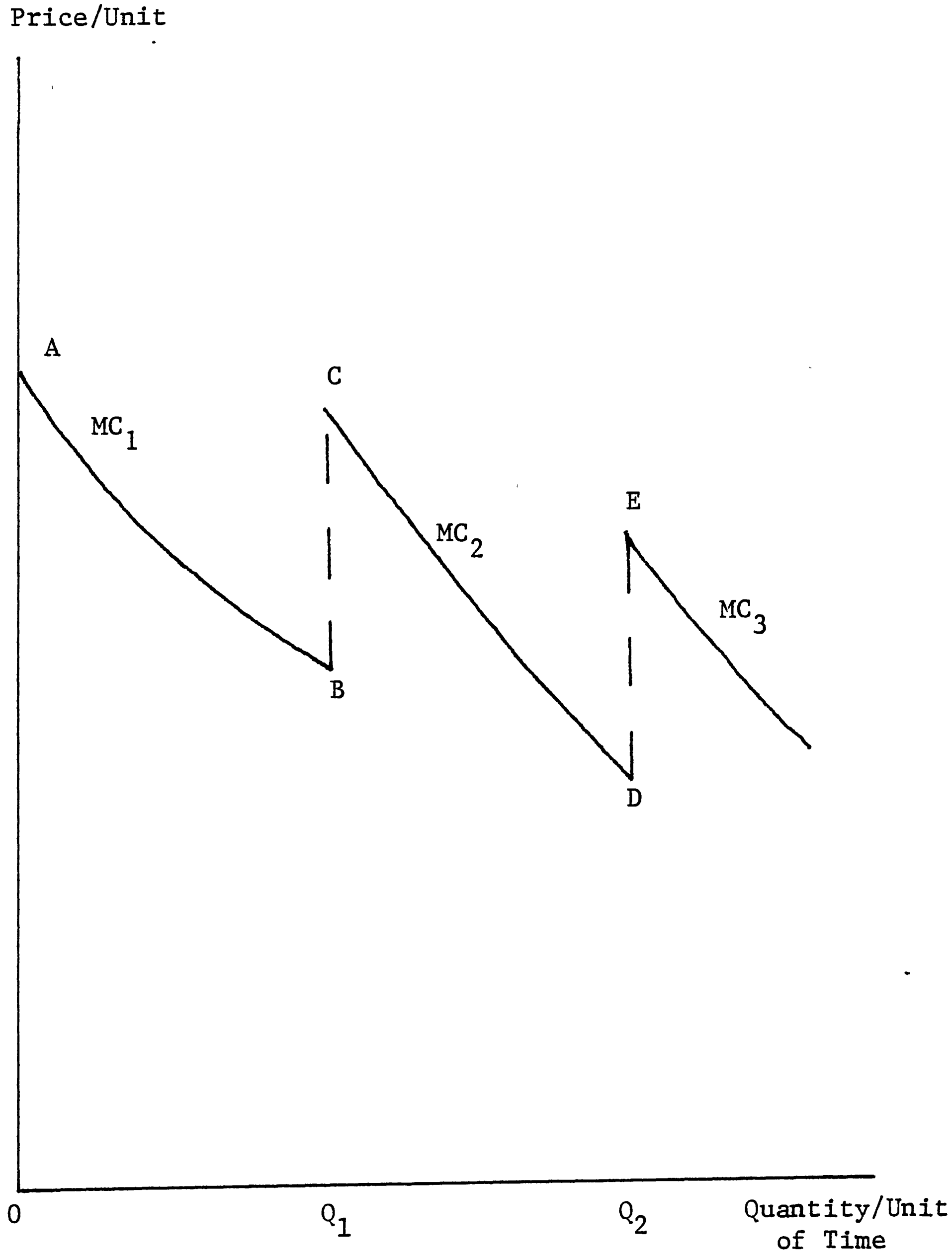


Figure 16. Interaction of Investment Cost and Operation and Maintenance

decreasing marginal cost. Quantities supplied beyond B result in increased capacity and in increased costs. This is represented by point C. The water system is now operating on MC_2. Economies of scale again occur as quantity demanded increase until quantity demanded exceeds quantity Q_2 at point D. Additional capacity is then needed and costs of operation increase to point E.

Combining Figures 15 and 16 the implications of a shifting demand function due to growth and economies of scale in capacity are shown in Figure 17. Assume the demand functions D_1, D_2, and D_3 represent a shifting demand due to population and income growth for years 5, 10 and 15 respectively. MC_1 represents the marginal cost with the initial capacity of the system. The net benefit for the system is equal to the area under the aggregate demand less the marginal cost of operating the system at point A where the demand function intersects MC_1. In year 10 the demand function has shifted to D_2 and capacity has been added. The system is now operating on MC_2 for pricing purposes. Net benefits are again equal to the area under aggregate demand D_2 less the marginal cost of operating the system at point B.

Losses would again occur using the strict marginal pricing approach. Using the individual household's demand equated to a block rate structure which intersects the demand at marginal price can be used to prevent losses to the rural water system.

Current Model Modifications

Myoung's model has subsequently been modified to incorporate the nonlinearity of the cost functions. Using a linear cost results in

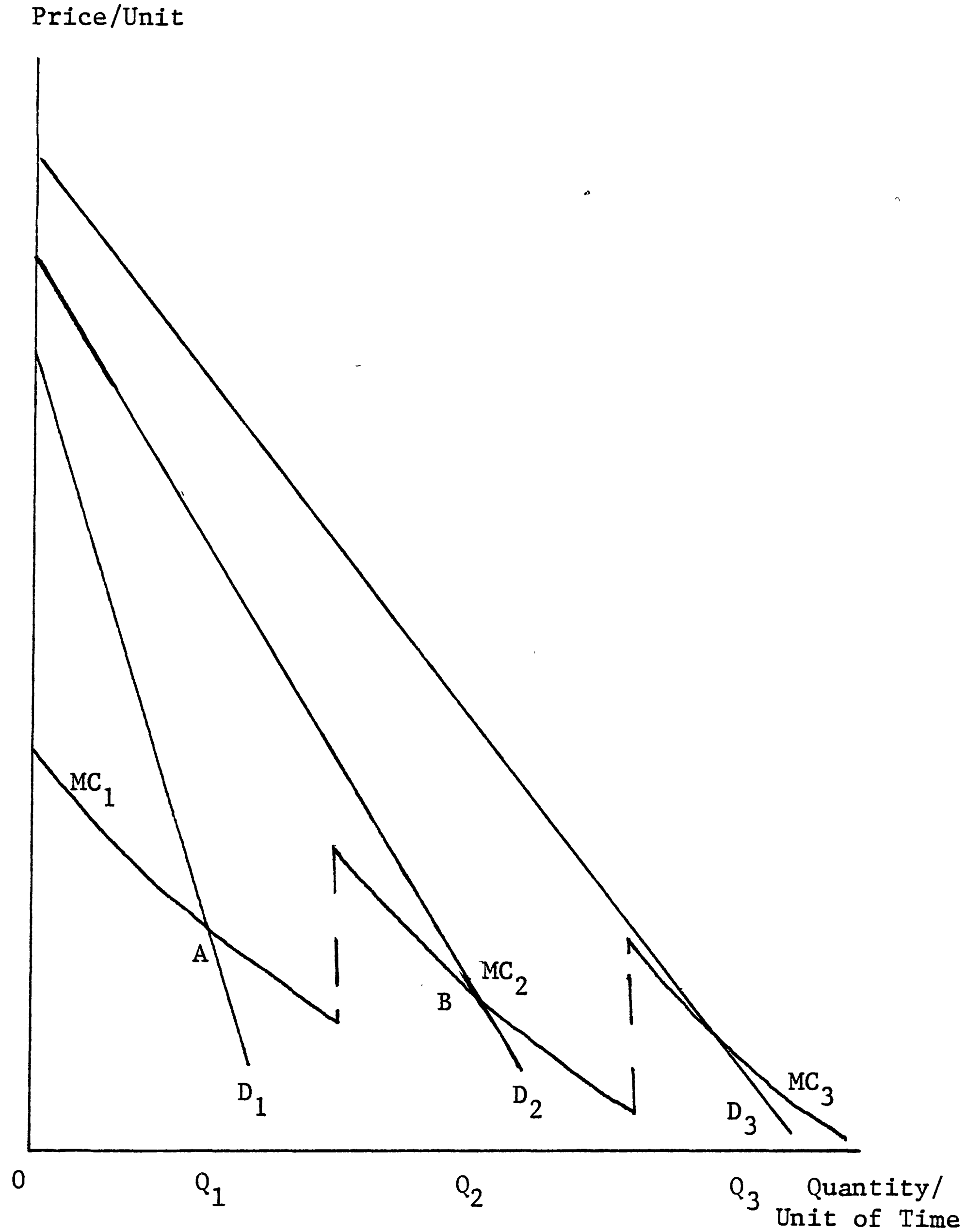


Figure 17. Multiple Period Investment

overestimating cost at small quantities of water supplied and underestimating cost at larger quantities. Dellenbarger, Myoung and Schreiner (1984) showed that there are seasonal and regional differences in the price elasticity for rural water in Oklahoma. The model has been designed to incorporate the seasonal differences in the demand for water.

It is hypothesized that there are differences in the demand for water resulting from different household characteristics such as age, family size, income and alternative uses and sources of water. Myoung used aggregate demand in his analysis. The model has been modified to use household demand rather than aggregate demand.

Distinctive Aspects of This Study

This study differs from Myoung's in several distinct approaches. Primary data were obtained from surveying rural water systems and households in the state of Oklahoma. Seasonal household demand is used in place of aggregate annual demand. Household income has been added as an additional variable. Separable programming is used to incorporate economies of scale in operation and maintenance and water purchases. Pricing policy implications for various user groups are examined.

CHAPTER III

RURAL WATER SYSTEMS CHARACTERISTICS AND COSTS

Introduction

Rural water systems in Oklahoma offer diverse characteristics. Differences occur in size of population, date of incorporation, water source and treatment, and financial (cost) situation. The households studied were also diverse. Rural water system users can be classified by profession, size of household, age, income and availability of alternative sources of water.

A two part survey was conducted to determine the characteristics of rural water systems and their users. The State of Oklahoma was divided into four quadrants using Interstates 35 and 40 as the dividing lines. One test rural water system was selected for the State in addition to five rural water systems from each quadrant. The sample of 20 systems was drawn at random from the list of members of the Oklahoma Rural Water Association. Inferences, therefore, should be limited to the population of Association members. Managers from each of the systems were contacted and asked if the rural water system would participate in the survey. If the system responded negatively another system was selected randomly from the same quadrant. Approximately eight systems responded negatively. This negative response could bias the sample results.

A Rural Water District Manager's Survey Questionnaire was mailed to each of the selected 21 systems. (The questionnaire is contained in Appendix A.) Two weeks later the selected water systems were contacted by phone and a date was selected for the surveyor to visit and answer any questions the manager or support staff might have in filling out the questionnaire. The period from initial contact by phone until the visit by the surveyor was approximately two weeks. During the visit to the 21 systems the rural water district manager's surveys were collected.

To increase the number of observations from the rural water district manager's survey an additional random sample of 145 questionnaires were mailed. Two rural water systems per county were randomly selected and mailed a survey with a self-addressed stamped envelope. If a manager did not respond after four weeks, a follow-up letter and questionnaire were again mailed. Each initial letter and follow-up letter contained a self- addressed stamped return envelope.

This chapter covers results on the Rural Water District Manager's Survey Questionnaire. The following chapter covers results of the rural household survey.

Rural Water System Characteristics

Of the 166 total rural water systems sampled, 87 responses were received. Of the 87 responses, 71 were usable. The response rate of the rural water system Manager's survey is contained in Table III. A test for nonresponsive bias was not made.

TABLE III

RESPONSE RATE FOR THE RURAL WATER SYSTEM SURVEY, OKLAHOMA, 1983

Surveys	Number	Percent
Surveys mailed	166	100
Surveys returned	87	52
Usable surveys	71	43

Rural Water System Incorporation

With the inception of Farmer's Home Administration (FmHA) in 1964, the number of rural water systems increased dramatically. This was due to the increased availability of grants and low cost loans. The results of the survey question asking when the rural water system was incorporated are contained in Table IV.

TABLE IV

INCORPORATION OF RURAL WATER SYSTEMS, OKLAHOMA, 1983

Year	Number of Respondents	Percent
1973-1983	12	17
1963-1972	44	62
Before 1963	9	13
No Response	6	8
	71	100

Between 1963 and 1983, 79 percent of the sample of systems were incorporated. The largest percentage of incorporation occurred between 1963-1972. This is associated with increased FmHA's funding for rural water systems. Only 13 percent of the sample were incorporated before 1963.

Source of Water

The southeastern region of Oklahoma has relatively abundant supplies of water in the form of streams and lakes. The northwest region is considerably drier than the southeast region and groundwater represents its supply of water. The water systems were asked for the source of water and were given the options of wells, streams, lakes or purchased water. The results of these two questions are contained in Table V.

TABLE V

SOURCES OF WATER AND WATER TREATMENT, OKLAHOMA, 1983

Sources of Water	Number Obs.	Percent
Systems which purchase water exclusively	24	34
Systems which treat purchased water	(3)	
Systems which use well water exclusively	29	41
Systems which treat well water	(8)	
Systems which use lake water exclusively	9	13
Systems which treat lake water	(7)	
Systems which use stream water exclusively	2	3
Systems which treat stream water	(2)	
Systems which blend water--	7	9
well and purchased	(6)	
lake and purchased	(1)	
Total	71	100

The largest number of systems surveyed use well water as their source. However, most of those using well water do not treat it. The second largest source of water was purchased water. Lake water as a source was similar to well water in that some systems did not treat it. For systems which blended water, purchased water was the most common denominator. Six systems blended purchased water with well water and one system blended purchased water with lake water.

Expansion of Systems

Rural water systems with their limited funding face a critical financial problem when expansion of the system occurs. Since rural water systems have shown significant decreasing unit costs it pays to build the largest size system that is economically feasible. The survey asked the rural water system's if expansion had occurred since initiation. The results are contained in Table VI.

TABLE VI

HAS THE RURAL WATER SYSTEM EXPANDED SINCE INITIATION?
SAMPLE SURVEY RESULTS FOR OKLAHOMA, 1983

Response	No. Obs.	Percent
Yes	59	83
No	10	14
No Response	2	3
	71	100

Since the percentage of new systems incorporated since 1963 is 79 percent and the number of rural water systems which have expanded since initiation is high it can be inferred that some of the systems which have been incorporated since 1963 have also faced expansion in a relatively short period of time. This would verify Myoung's finding that most rural water system's do not start with the optimal capacity, and hence must expand in size sooner than the optimal.

The reason for this lack of optimal initial capacity can be explained by several factors. Due to the relatively small size of the systems the financial capabilities of the systems may limit initial capacity. Lending policies by the FmHA rely on projected growth and average per capita usage. Projected growth can be under- or over-estimated and usage can be influenced by the price of water. These factors can influence decisions on size of the initial system and thus subsequent expansions. Uncertainty about the availability of water supplies, funding, growth of the system and financial considerations also influences the initial capacity and expansion process. The types of expansions and their frequency for the rural water systems are contained in Appendix B.

Connection of New Customers

Rural water systems are unique in that the systems can represent towns or the country side. The factors influencing the connection of new customers are distance from the current lines to additional customers, the financial situation of the water system and the availability of water supplies. Rural water systems participating in the survey were asked if they were encouraging the connection of new customers. The results are contained in Table VII.

TABLE VII

IS THE RURAL WATER SYSTEM ENCOURAGING THE CONNECTION OF NEW CUSTOMERS? SAMPLE SURVEY RESULTS FOR OKLAHOMA, 1983

Response	No. Obs.	Percent
Yes	51	72
No	15	21
No Response	5	5
	71	100

The majority of the systems were encouraging the connection of new customers. The surveyor in talking with representatives of the 21 systems that he visited found that those systems which were encouraging the connection of new customers were doing so in the hopes of increasing revenue. Those systems which were not encouraging the addition of new customers were doing so either to preserve the size of the current system or for financial reasons. Preserving the size of system was viewed in part as keeping the nonmetropolitan atmosphere and a rural flavor. Financial reasons for not expanding the system were due to the relatively long distances between customers in the contingent areas.

The consideration of adding new customers was influenced somewhat by the rural water system being adequately able to meet seasonal demand. The results of the survey showed that 66 percent of the systems could adequately meet seasonal demand. However, 30 percent responded that the system could not meet seasonal demand and 4 percent did not respond to the question.

Water Quality

Water quality is often taken for granted, but it can vary greatly. In rural areas the quality can be influenced by nitrates which have entered into the water source. The age of the system can also influence taste and color of the water through rusted pipes. Rural water system managers were asked if the system had problems of water quality such as odor, color or taste. The results are contained in Table VIII.

Of system managers surveyed, 72 percent did not feel that there was a problem of water quality. However, 28 percent of the system managers did believe there was a problem.

Rural Development

Rural development can take many forms. It can be used to help prevent people from moving to other areas or to increase the population. Improving fire protection or trying to attract business are included in rural development. Questions dealing with rural development were asked and the responses are contained in Appendix B. A critique of the responses is given below.

TABLE VIII

DOES THE RURAL WATER SYSTEM HAVE PROBLEMS WITH WATER QUALITY? SAMPLE SURVEY RESULTS FOR OKLAHOMA, 1983

Response	No. Obs.	Percent
Yes	20	28
No	51	72
No Response	0	0
	71	100

A majority of the systems surveyed felt that the rural water system had helped keep people from moving and had actually helped to increase population in the area. An increased rate of home construction and an improvement in fire protection were attributed to the rural water system. The majority also felt that the rural water system had not helped create new job opportunities, attract new business firms, expand existing businesses or increase livestock operations.

Size of System

The size of the rural water system is influenced by several factors including whether the system is located close to a suburban area versus a rural or farming community, the financial strength of the system and whether the area has supporting industry. Size can be measured in the number of taps or the length of the water lines in miles. The number of taps per system is contained in Table IX.

Systems which fall in the range between 101-700 users include 56 percent of the respondents. Systems serving over 1101 users constitute 17.5 percent of the respondents. The typical rural water system can thus be categorized as one that serves less than 700 taps. This typical system could be a small town, a rural suburb or a rural area. When asked the question of the number of miles of line the system had in 1983 the mean length was 112 miles. The maximum length was 300 miles and the smallest system had one and a half miles.

TABLE IX

NUMBER OF TAPS PER SYSTEM FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Number of Taps	No. Obs.	Percent
Less than 100	6	8
101- 300	19	26
301- 500	11	16
501- 700	10	14
701- 900	3	4.5
901-1100	0	0
1101-1300	6	9
1301 and over	6	8.5
No response	10	14
	71	100

Financial Situation

The rural water system managers were asked to list total revenues and expenditures for 1983. From this the 1983 net cash flow was obtained. The financial situation of the sample of rural water systems for 1983 is contained in Table X. The frequency of positive and negative net cash flow in thousands of dollars are contained in Appendix B.

TABLE X

FINANCIAL SITUATION OF A SAMPLE OF RURAL WATER SYSTEMS FOR OKLAHOMA, 1983

	No. Obs.	Percent
Positive Net Cash Flow	38	54
Negative Net Cash Flow	20	28
No Response	13	18
	71	100

Of the respondents, 28 percent operated at a negative cash flow in 1983. The maximum positive cash flow was $119,723 compared to a maximum negative cash flow of $61,231. Of the rural water systems, 29 percent operated with a positive cash flow greater than $21,000.

The results of the surveyor's visits to the 21 rural water systems coincide with the results of the financial situation of rural water systems. Several of the rural water systems visited acknowledged the fact that they were struggling financially. On the other end of the spectrum several rural water systems had invested cash reserves in certificates of deposit. All except one of the systems visited which showed positive cash flows were encouraging the connection of customers.

Regional Differences

It was hypothesized that there would be regional differences among the rural water systems. The state was divided into four regions using Interstates 35 and 40 as the dividing lines. Of the 71 respondents, 14 were from the northwest, 17 from the northeast, 26 from the southeast and 14 from the southwest.

Due to the more arid conditions of the western half of the state, it was hypothesized that the use of well water as the primary source would be more prevelent than in the eastern portion of the state. The results are contained in Table XI.

TABLE XII

PRIMARY SOURCE OF WATER BY REGION FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

	Wells	Streams	Lakes	Purchased	No Response	Total
	Number					
Northwest	12	0	1	1	0	14
Southwest	11	0	1	1	1	14
Subtotal	23	0	2	2	1	28
Northeast	2	0	4	10	1	17
Southeast	7	2	3	14	0	26
Subtotal	9	2	7	24	1	43
Total	32	2	9	26	2	71

The results bear out the hypothesis. Of the 28 respondents from the western portion of the state, 23 used well water as the primary source of water. The eastern half of the state showed a high dependence on purchased water. For the eastern portion of the state, 24 systems used purchased water of the 43 respondents.

Due to the large use of well water in the western portion of the state and the use of purchased water in the eastern part of the state the treating of water was not assumed to have regional connotations. Results of the regional differences for the treatment of water are contained in Table XII.

TABLE XII

REGIONAL DIFFERENCES FOR WATER TREATMENT FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

	Yes	No	No Response	Total
Northwest	4	9	1	14
Southwest	4	9	1	14
Subtotal West	8	18	2	28
Northeast	8	8	1	17
Southeast	7	18	1	26
Subtotal East	15	26	2	43
Total	23	44	4	71

Appendix B contains a breakdown on regional differences for several of the survey questions. A brief overview of these results follows.

All regions showed that a majority of the rural water systems are encouraging the connection of new customers and a majority of the systems in each region have expanded since initiation. The average size of the system varied by region. The northwest had the smallest average size system with 233 taps. The northeast region had the largest average size with 824 taps. The southeastern and southwestern regions had the same approximate size at 581 and 560, respectively.

Also contained in Appendix B are the regional results of the eight development questions. When asked if there was an increase in the rate of home construction every region had a majority to the affirmative except the northwest region. All regions had a majority which responded yes to the question of whether the rural water district had helped increase population, improved fire protection, and increased property values. Only the southwest region had a majority which felt that the rural water system had increased livestock enterprises. No region had a majority which felt that the rural water system had created new job opportunities, attracted new business firms or helped with the expansion of business firms.

Rate structures for the 71 systems differ greatly. The differences arise in type of structure whether decreasing block, increasing block, or flat rates. Also differences arise from the amount of service charge for an initial quantity and the amount of initial quantity covered by the service charge. The rate structures for the 71 systems are contained in Appendix C and discussed further in a later chapter.

Surveyor's Perceptions Resulting From Visiting 21 Systems

After visiting the 21 systems the surveyor observed that there were several distinct classes of rural water systems. The classes can be distinguished on philosophy and on type of system.

As stated earlier the systems can be distinguished between those serving farming communities, suburbs and rural areas. Some systems also try to present an image. Five of the systems had elaborate offices and felt that the customers would view this as the system being run in an efficient manner or would be able to take pride in the operation. Other systems were operated out of a board member's home, place of work or small office.

Six of the systems visited appeared to be maximizing current revenue and to be emphasizing addition of new customers. For some systems, the views of the manager were often in conflict with other members of the board of directors. The differences ranged from type of service to be provided, how the cash reserves should be spent such as reinvestment, and the direction of the system such as attracting new customers.

It appeared to the surveyor that there is a class of managers who go from system to system improving a system's financial situation to the point of considerable cash reserves. Upon reaching such a status the manager then becomes expendable and is replaced. The manager then goes to a new system which is in financial trouble and brings it up to profitability. This type of manager basically is a trouble shooter.

Another problem rural water systems face is in the area of financial record keeping. Approximately ten of the systems kept their financial records on a yellow legal pad. Record keeping was kept to a minimum. Most board members are elected as representatives of customer groups and have little knowledge on operation of rural water systems. Nevertheless, board members frequently deviate from established policy and override the manager's operational decisions. In one instance, the previous board members had burned the records of their dealings and the current board members were facing bills with no record of expenditure.

Costs of Rural Water Systems

Data from the current Rural Water District Manager's Survey were supplemented with data from earlier surveys and studies to estimate costs of rural water systems. Costs have been disaggregated into (1) operation and maintenance, (2) water purchase, and (3) investment. Current survey results were used to estimate operation and maintenance costs for a sample of systems using purchased water as their water source and for a sample of systems using well water as water source. These results are compared to previous studies for rural Oklahoma systems.

Water purchase and investment costs were taken from a previous study (Myoung, 1982). Investment costs are limited to a sample of systems that purchased water so investment is related only to water distribution. All cost estimates from previous studies have been indexed to 1983 cost levels for purposes of cost comparison. Costs of operation and maintenance and water purchase were estimated on an annual basis.

Operation and Maintenance

The current survey data were used to estimate average cost of operation and maintenance (O&M) for (1) a sample of systems purchasing water from another system and (2) a sample of systems obtaining water from wells. For (1) above, the cost of purchased water is not included in the O&M cost functions. Since information was not available on capacity of the systems it had to be assumed that observations represented close approximations to long run average costs for operation and maintenance.

The functional form used for estimation of average operation and maintenance cost is:

AONDM = $f(Q, Q^2)$

where

AONDUM = annual average operation and maintenance cost per thousand gallons of water

Q = water supplied per year in millions of gallons

The average cost functions are presented in Table XIII.

Average operation and maintenance cost per thousand gallons of water was $1.69 for systems purchasing water and $1.10 for systems using well water. The range of the data was from $1.06 to $2.14 for systems purchasing water and from $0.17 to $2.45 for systems using well water. All data are in 1983 dollars. The average size of the system was 55.320 million gallons for systems purchasing water and 81.539 million gallons for systems using well water. The range of the size of system was from 35,615 gallons to 343,000,000 gallons per year for those systems purchasing water and from 12,000,000 to 269,600,000 million gallons per year for those systems using well water. The signs of the independent variables are as expected. However, only the intercept terms and the linear term for the systems purchasing water are significantly different from zero at the five percent probability level.

Both systems exhibit convex average operation and maintenance cost functions. However, the minimum average O&M cost is at 166.7 million gallons for the systems purchasing water and 750 million gallons for the systems using well water.

TABLE XIII

REGRESSION RESULTS FOR OPERATION AND MAINTENANCE COST PER THOUSAND GALLONS OF WATER, SAMPLE OF RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Independent Variables			No. Obs.	Adj. R^2
	Intercept	Q	Q^2		
	Systems Purchasing Water				
Coefficient	1.79[a]	-0.002[a]	0.000006	15	0.47
Standard Error	0.26	0.00069	0.000007		
Mean		55.32			
	Systems Using Well Water				
Coefficient	1.46[a]	-0.006	0.000004	11	0.36
Standard Error	0.35	0.0079	0.000005		
Mean		81.539			

[a] Statistically significant at the five percent probability level.

These results are contrasted with results of an earlier study by Myoung and Schreiner. The earlier study was limited to systems purchasing water. Averge O&M cost per thousand gallons of water was \$0.48 in 1967 prices which when adjusted to the 1983 price level equals \$1.31 per thousand gallons of water. The minimum average O&M cost occurred at 220.82 million gallons.

Water Purchase Cost

In an earlier study, the cost of water purchased was separated from cost of operations and maintenance (Dellenbarger, Myoung and Schreiner, 1983). It was hypothesized that purchase cost need not necessarily be a function of quantity of water taken but a function of year in which purchased. It was thought that the purchase cost of water might be increasing with time if water is becoming more scarce in rural areas. The following function was estimated:

$$WPDWASD = f(Q, Q^2, TIME)$$

where

WPDWASD = annual average purchase cost of water per thousand gallons

Q = annual water purchased per year in millions of gallons

TIME = year of purchase with 1970 coded as one

Results of the estimated function are presented in Table XIV. All costs were inflated to 1983 dollars. Average purchase cost of water was \$0.87 per thousand gallons. Purchased cost ranged from \$0.16 to \$3.00 per thousand gallons.

TABLE XIV

REGRESSION RESULTS FOR WATER PURCHASE COST PER THOUSAND GALLONS OF WATER, SAMPLE OF RURAL WATER DISTRICTS, OKLAHOMA

	Independent Variables				No. Obs.	Adj. R^2 %
	Intercept	Q	Q^2	TIME		
Coefficient	1.36[a]	-0.01[a]	0.00003[a]	-0.022	78	0.45
Standard Error	0.098	0.0025	0.00000	0.018		
Mean		50.006		6.68		

[a] Statistically significant at the five percent probability level.

Source: Dellenbarger, Lynn E., Kwang-Sik Myoung and Dean F. Schreiner. "Economics of Rural Community Water Demand and Supply in Oklahoma," Paper presented at Mid-Continent Regional Science Association meetings, Oklahoma City, OK, June 5-7, 1983.

Neither hypothesis proved to be valid. Quantity of water purchased proved to be statistically significant in explaining average purchase cost of water. Purchase cost of water apparently decreased for later years rather than increased although the regression coefficient is not statistically significant at any reasonable probability level. Purchase cost of water showed a convex curve with minimum cost at 166.67 million gallons. The range of the annual water purchased was from 5.15 million gallons to 305.40 millions of gallons.

Investment Cost

The current survey did not obtain data on investment costs of rural water systems. Therefore, results of an earlier study were used for the present analysis. A total investment cost function was estimated in the following form:

$$INV = f(C, C^2, D)$$

where

INV = total investment cost in 1983 dollars

C = capacity of the water system in millions of gallons of water per year

D = density expressed in number of taps per mile

Capacity was determined by measuring quantity of water supplied just prior to a major addition to the system such as increased storage facilities, booster pump or parallel lines. All investment costs were inflated to 1983 dollars for purposes of comparing systems.

Results of the estimated total investment cost function are contained in Table XV. The sample mean for total cost is $1,242,898. The sample mean for average investment cost per thousand gallons is

TABLE XV

REGRESSION RESULTS FOR TOTAL INVESTMENT COST FOR A SAMPLE OF RURAL WATER DISTRICTS, OKLAHOMA

	Independent Variables					Adj.
	Intercept	C	C^2	D	No. Obs.	R^2 %
Coefficient	829,671.77[a]	8558.62[a]		-11948.74	18	0.77
Standard Error	166,779.34	1103.83		17644.48		
Mean		47.774		7.92		
Coefficient	850,671.96[a]	7533.95	3.38	-10383.44	18	0.75
Standard Error	192,744.92	4369.51	13.91	19330.78		
Mean		47.774		7.92		

[a] Statistically significant at the five percent probability level.

Source: Dellenbarger, Lynn E., Kwang-Sik Myoung and Dean F. Schreiner. "Economics of Rural Community Water Demand and Supply in Oklahoma," Paper presented at Mid-Continent Regional Science Association meetings, Oklahoma City, OK, June 5-7, 1983.

$38.75 with a range of $12.22 to $73.00. The average capacity was 47.774 million gallons per year with a range for the sample of 10.2 million gallons to 305.4 million gallons.

Conclusions

Results of the Rural Water Systems Manager's Survey were presented. Of 166 surveys mailed, 71 usable surveys were obtained for a 43 percent response rate.

Of the systems responding, 79 percent were incorporated after 1963. Also, 83 percent of the systems expanded since initiation. This leads to the conclusion that the first expansion of most rural water systems occurs within 20 years from incorporation.

The encouragement of new customers is favored by 72 percent of the systems, but 30 percent of the systems also stated that they could not meet seasonal demand. It is therefore possible that some systems are encouraging the connection of new customers to increase revenue while realizing the customers may not be able to have adequate water during some periods.

Financially 54 percent of the systems had positive cash flows whereas 20 percent were operating with a negative cash flow. The maximum positive cash flow was $119,723 compared to the maximum negative cash flow of $61,231.

Cost functions for operation and maintenance, water purchase and investment were estimated. Average cost functions for the operation and maintenance and water purchase show convex curves indicating economies of scale exist for rural water systems over a wide range of outputs.

CHAPTER IV

RURAL HOUSEHOLD CHARACTERISTICS AND WATER DEMAND

Introduction

A sample of 21 rural water systems were visited with five from each quadrant in the State of Oklahoma and one test system in the northeast quadrant. Selection of the sample was discussed in the previous chapter. Of the 21 systems visited, 14 provided addresses of household users in their system. A ten percent sample of households in each system were mailed a Rural Water System Household Survey questionnaire (Appendix D) with a self-addressed return envelope. If after three weeks a household had not responded, a follow-up letter, survey questionnaire and a self-addressed return envelope were mailed to that household. A response rate of 53 percent was obtained for the household survey (Table XVI). Nonresponse bias from either those systems not furnishing addresses or those households not returning the survey was not tested.

This chapter presents characteristics of the rural households that form rural water systems in Oklahoma. Household demand functions for rural water services were estimated based on survey data and water consumption and price data available at the water district level.

TABLE XVI

HOUSEHOLD SURVEY RESPONSE RATE FOR A SAMPLE OF RURAL WATER SYSTEMS, OKLAHOMA, 1983

Surveys	Number	Percent
Surveys Mailed	668	100
Surveys Returned	356	53
Usable Surveys	347	52

Rural Household Characteristics

Household Size

The average size household of those households included in a sample of rural water systems was 2.83 people with a range of one to 12 people. The largest category of individuals was a family size of two individuals. At least 48 percent of the households were limited to one or two members. The results of the survey on frequency of household size are contained in Table XVII.

TABLE XVII

FREQUENCY OF HOUSEHOLD SIZE FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Number of Persons Per Household	No. Obs.	Percent
1	52	15
2	117	33
3	59	17
4	49	14
5	30	9
6	6	2
over 6	7	2
No response	27	8
	347	100

Age Distribution

The results of the survey show that 19 percent of the population were sixty years of age or over. Sixteen percent of the population were 10 years or younger and 31 percent were 19 years or younger. The results by age distribution are contained in Table XVIII. When compared to the population distribution in 1980 for the state of Oklahoma, 16 percent were sixty and over and 32 percent were 19 years or younger.

TABLE XVIII

DISTRIBUTION OF HOUSEHOLD MEMBERS BY AGE GROUP, FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Age	No Obs.	Percent
0- 5	77	9
6-10	65	7
11-14	62	7
15-19	75	8
20-29	104	12
30-39	101	11
40-49	117	13
50-59	124	14
60 +	175	19
	900	100

Household Income

Households respondents were asked to answer a question designed to determine there gross income. Income categories were given and the respondent was asked to mark which one included their household. Of the responding households, 41 did not respond to this question. The category of household income between $10,000 to $15,000 contained the largest percentage of households, 17 percent. About 23 percent of

TABLE XIX

HOUSEHOLD INCOME FOR SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Income ($)	No. Obs.	Percent
0 - 5,000	30	10
5,001 - 10,000	40	13
10,001 - 15,000	52	17
15,001 - 20,000	22	7
20,001 - 25,000	47	15
25,001 - 30,000	19	6
30,001 - 35,000	26	8
35,001 - 40,000	17	6
40,001 - 45,000	12	4
45,001 - 50,000	9	3
50,001 - 55,000	8	2
55,001 - 60,000	12	4
60,001 - 70,000	2	1
70,001 - 80,000	5	2
80,001 - 90,000	0	0
90,001 - 100,000	4	1
Over 100,000	1	1
	306	100

the households had annual incomes of $10,000 or less and 47 percent had incomes of $20,000 or less. The results of the household income characteristics are contained in Table XIX.

Of the households which responded to the survey, 11 percent had annual incomes of over $50,000. The median family income was $22,500. This compares with the median family income for all of Oklahoma of $17,668 for the year 1979 which when expressed in 1983 price equals $24,250.

Occupation of Head of Household

Respondents were asked to circle the occupation of the head of the household. They were given 12 choices including the option of listing a "not specified" category. Of the 347 respondents only eight failed to respond. The four top responses were retired, professional, laborer and farmer. These four responses comprised 61.5 percent of the respondents (Table XX). Interestingly, farmers and farm workers accounted for only 11.5 percent of occupation of head of household for the sample of residents in rural water systems.

Other factors relevant to occupation are the normal work week in hours and driving distance to work one way. The mean hours worked was 34.8 hours with a range from zero to 74 hours. Driving distance to work had a mean value of 9.98 miles and ranged from zero miles to 80 miles.

TABLE XX

OCCUPATION OF HEAD OF HOUSEHOLD FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Occupation	No. Obs.	Percent
Professional	45	13
Manager; administrator	38	11
Sales; clerical	10	3
Craftsman	16	4.7
Laborer; operator	42	12
Service worker	7	2
Farmer or farm worker	40	11.5
Housewife	5	1.5
Student	1	.3
Retired	88	25
Not employed	8	2
Not Specified	39	12
No Response	8	2
	347	100

Type of Residence and Other Locational Information

Several questions involved the type and length of residence. For type of residence respondents were asked to circle one of four options: mobile home, house, duplex or apartment. The results are contained in Table XXI. The overwhelming majority of type of residence was homes with 87 percent. Mobile homes comprised 12 percent.

Households were also asked if they were one of the original rural water district members. Of the respondents, 114 responded yes and 209 responded negatively. No response accounted for 24 households. The typical length of residence was 14 years with the minimum period being one year and the maximum being 67 years.

Another question asked was when did the household first get their water from their rural water system. The mean year was 1973 with the earliest being 1917 and the latest 1983.

Of interest to the surveyor was where the rural residents came from prior to locating in their current residence. The households were given four choices and the.results are contained in Table XXII.

Most respondents moved to their present location from other locations within Oklahoma. Those moving from either their same county or within the same rural water district accounted for 54 percent of the respondents. When asked what type of area they moved from, 46 percent responded that they had moved from a town. Those moving from a farm or rural nonfarm area accounted for 33 percent. Only 10 percent responded that they came from an urban area.

TABLE XXI

TYPE OF RESIDENCE FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Type	No. Obs.	Percent
Mobile Home	41	12
House	301	87
Duplex	1	0.3
Apartment	3	0.4
No Response	1	0.3
	347	100

TABLE XXII

PRIOR LOCATION OF HOUSEHOLDS FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Previous Residence	No. Obs.	Percent
Location in same rural water district	85	24
Location in same county	105	30
Location in Oklahoma	75	22
Location outside Oklahoma	45	13
No Response	37	11
	347	100

Reason for Moving to Rural Water District

Six answers were provided to the households to determine their reason for moving to a rural water district. There were many reasons for moving to the rural water district. Households moved due to transfers by employers or to obtain employment. Other reasons were to change lifestyle or for a preference for rural living. Other results are provided in Table XXIII. The most widely selected answer was preference for rural living. The category "other" was the second most widely selected answer. Answers provided for this response covered such things as "got married" or "move close to parents".

TABLE XXIII

REASON FOR MOVING TO A RURAL WATER DISTRICT FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Reason	No. Obs.	Percent
To obtain employment	17	5
Transfer by employer	12	3
Preference for rural living	119	34
To change lifestyle	32	10
Dislike for other residence	19	5
Other	96	28
No Response	52	15
	347	100

Water Quality and Water Usage

Several questions were asked concerning the use of water and its perceived quality. When asked to compare the quality of their current water with the water they were using before, 47 percent felt it was as good as, 22 percent felt it was worse than, and 20 percent felt it was better than their previous water. A total of 11 percent failed to respond to the question.

Five additional questions dealt with types of nonhousehold water use and also the availability of water. These results are contained in Table XXIV.

Most rural water system users felt that they could use as much water as they wished. The majority also used water to wash their cars. About the same percentage of people used water for gardens as didn't, but more households didn't use water for lawn sprinkling and for livestock enterprises than did. The next section deals with alternative sources of household water. The hypothesis presented is that most households do have an alternative source of water for nonhousehold use.

Alternative Sources of Water for Household and Nonhousehold Use

Eight questions were asked of the households to get an understanding of the relationship between household and nonhousehold water use. Of the systems surveyed, the mean amount of water used for household purposes was 86 percent and for nonhousehold purposes it was 14 percent.

TABLE XXIV

HOUSEHOLD WATER USAGE FOR A SAMPLE OF RURAL WATER SYSTEMS IN OKLAHOMA, 1983

Question	Yes	(%)	No	(%)	No Response	(%)
Are you able to use as much water as you like?	267	(77)	51	(15)	29	(8)
Do you use water from the system to wash your car?	176	(51)	121	(35)	50	(14)
Do you use water from the system to water your garden?	142	(41)	145	(42)	60	(17)
Do you use water from the system for lawn sprinkling?	103	(30)	177	(51)	67	(19)
Do you water livestock from the system?	107	(31)	226	(65)	14	(4)

For the question of do you have an alternative source of water for household use or nonhousehold use the response was as follows. Of 304 respondents, 20 or 6.6 percent responded that they had alternative sources of water for household use. For 327 respondents, 101 or 30.9 percent responded that they did have alternative sources of water for nonhousehold use.

When asked what percent of their household water was from their rural water district, 327 households responded and the mean amount was 98 percent.

The households were also asked to determine what percent of their nonhousehold water came from their rural water system versus alternative sources. The mean amount of nonhousehold water use from alternative sources of water was 25 percent.

Rural Household Water Demand

Oklahoma's seasonal weather varies substantially. During the summer it is hot and arid compared to the relatively cold moist winter. Spring and fall are periods of transition. Due to the changing seasonal patterns it was assumed that four distinct seasonal demand functions could be estimated. Winter was assumed to begin in January and encompassed January, February, and March. Spring was assumed to comprise April, May and June. July, August, and September are representative of summer. The remaining three months, October, November and December comprise fall. The monthly seasonal water prices and water bills were averaged for the four seasons and a marginal price and difference variable were obtained.

Household Demand

Little definitive research has occurred on estimating rural water demand using household data. Most research on water demand has been for urban systems (see the review of price elasticity studies in Chapter II) or using aggregate cross section data of rural systems (Dellenbarger, Myoung and Schreiner, 1984).

Urban household water demand is expected to differ substantially from rural water service demand. First, urban households have fewer (if any) alternatives to the public water system. Rural households frequently have one or more alternative sources of water, particularly for nonhousehold use. These alternative sources include wells, ponds and streams. Second, rural households generally have a wider array of uses for water than do the urban households. While both may have similarities in use of water for household and lawn sprinkling purposes, rural households are expected to have larger gardens and orchards, greater frequency of livestock and poultry enterprises, and other farm related water needs such as for crop spraying.

Household data should be superior to cross section system data in estimating water demand since it allows a closer approximation to the marginal price of water and it allows closer approximations of household characteristics such as size of household, family income and whether households have alternative sources of water. Furthermore, under usual schemes of pricing water, such as decreasing or increasing block rate structures, households do not face a single price for water but a multiple tier of water prices one of which becomes the marginal price but all of which are incorporated in the budget constraint.

analysis. Aggregate water system demand estimation procedures generally tend to result in use of some form of average price for water.

Sign of the Difference Variable

The expected sign of the difference variable as explained in an earlier chapter depends upon whether households are facing a decreasing block rate or an increasing block rate. When comparing consumers surplus under block rate structures with consumers surplus under marginal price, increasing block rates have greater consumers surplus and decreasing block rates have lower consumers surplus. Billings and Agthe (1980) and Howe (1982) show that the expected sign of the difference variable is negative under increasing block rate and positive under decreasing block rate.

However, it is not apparent that the difference variable should be linear as contained in the Billings and Agthe and Howe studies. The difference variable is defined as:

$$D = WB - P_e Q_e$$

where WB equals the actual water bill per billing period, and Q_e is the quantity consumed during the billing period. The marginal price of the quantity consumed is represented by P_e. Assume the rate structure of Figure 18 exists and that SC represents the average unit price of the Q_1 gallons for the flat rate (i.e. minimum monthly service charge for use of water up to Q_1 gallons) and that the marginal price is P_4. Also assume the four households H1, H2, H3 and H4 exist. Household H1 consumes Q_1 gallons so its marginal price is P_2. The value of D would be area 1 (it would be irrational

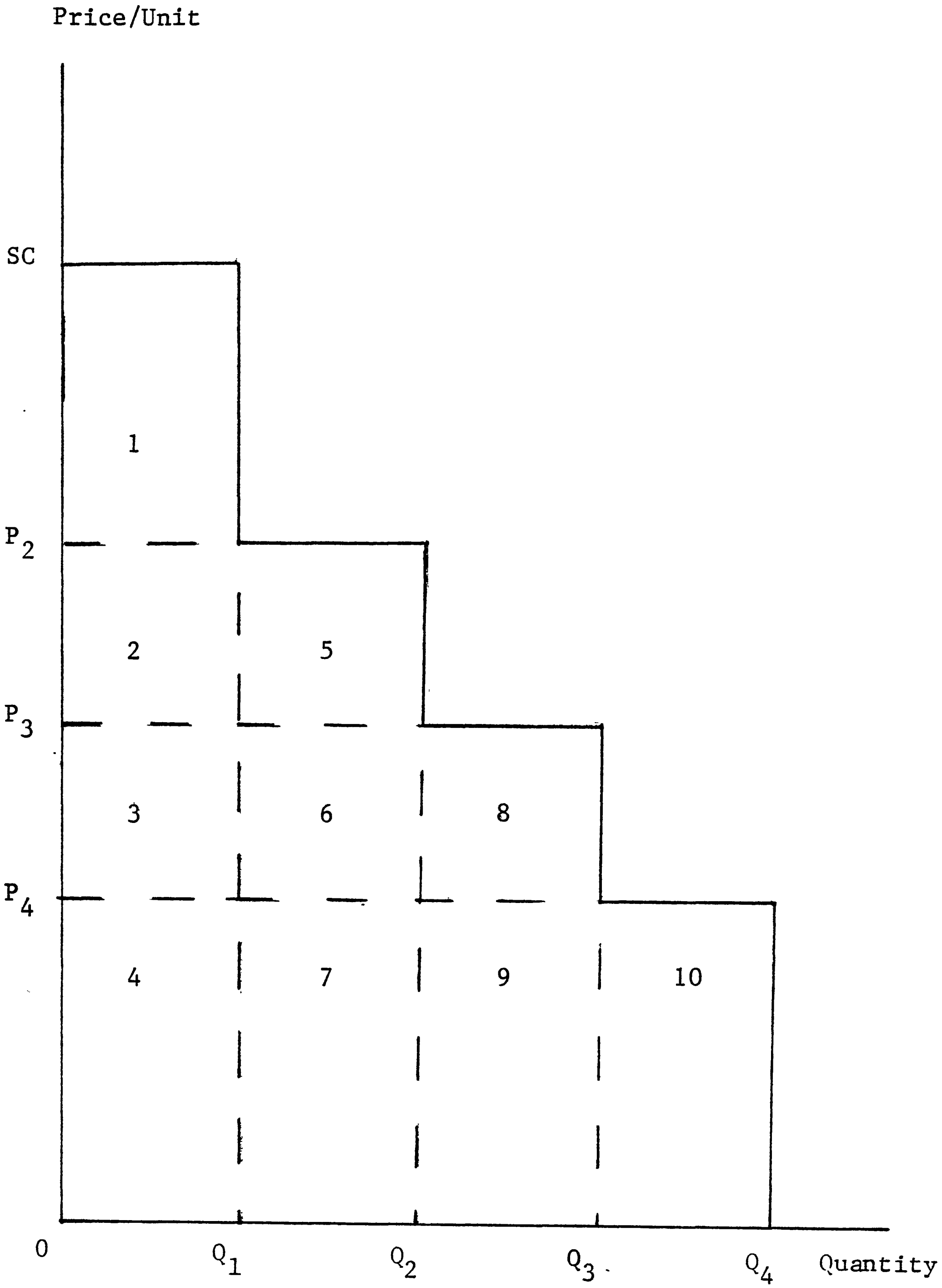


Figure 18. Rate Structure

for any household to consume less than Q_1 since marginal cost is equal to zero). Household H2 consumes Q2 less one gallon so its marginal price is equal to P_2 and D is again equal to 1. Household H3 consumes Q_3 less one gallon so it has a marginal price of P_3 and a D value of 1+2+5. Finally, household H4 consumes Q_4 less one gallon so it has a marginal price of P_4 and a D value of 1+2+3+5+6+8. Clearly for this sample of four households the relationship between Q and D is positive but nonlinear. The relationship of D to water consumed depends on the monthly minimum service charge, the number of price tiers and the price difference between tiers.

Seasonal Rural Water Demand for Oklahoma

A random sample of rural water systems for Oklahoma was drawn and a ten percent random sample of each system's customers was identified. Actual 1983 monthly water consumption and water billings data were recorded for the ten percent samples and a mail questionnaire was sent to the customer to obtain income and household characteristic data. Monthly data for each household were aggregated to quarters and then a monthly average consumption and water bill by quarter were computed. Based on the water system rate structure, the marginal price, difference variable and intramarginal price tier quantities were computed. Because rural water meters are not always read on the same day of the month and because some months are estimated, it was felt that monthly averages by quarter would be better approximations of actual monthly usage than the monthly data itself. The quarters were taken commencing with January and ending with December.

A total of 347 households responded representing 14 different rural water systems. Of these, a total of 296 usable quarterly observations resulted. Lack of household income data accounted for the major reduction in usable observations. Bias may enter the estimates from nonresponse to the survey and nonresponse to income information.

The following quarterly demand function resulted from OLS estimation:

$$\begin{aligned} MW = {} & \underset{(3.52)}{12.801} - \underset{(-2.96)}{9.469MP} + \underset{(2.22)}{1.879MP^2} - \underset{(-1.12)}{0.691D} + \underset{(2.29)}{0.077D^2} \quad (t) \\ & + \underset{(3.60)}{1.172SIZH} + \underset{(2.78)}{0.064INCOM} - \underset{(-0.60)}{0.0059NHALT} \qquad (4.1) \end{aligned}$$

$$R^2 = 0.29, \quad F = 16.59$$

where

MW = average monthly water usage by quarter per household in thousands of gallons

MP = marginal price in dollars per thousand gallons

D = difference variable and is equal to the actual water bill less the water bill if water was priced at the marginal price

INCOM = 1983 annual household income in thousands of dollars

SIZH = number of people in household

NHALT = percent of nonhousehold water from alternative sources

All signs of the variables are as expected and all coefficients are statistically significant from zero at the five percent probability level or better except D and NHALT. The adjusted R^2 is 0.29 and the F statistic is statistically significant at the 0.0001 probability level.

The demand function was then tested for quarterly (seasonal) differences in intercept and slopes of the marginal price and difference variables. The tests for standard stability are contained in Appendix E. It was found that there were quarterly differences in the intercepts and slopes. Choosing the first quarter (January-March) as a standard for most nearly reflecting only household demand for water, all other quarters were tested against this quarter for differences in intercept and slopes of the marginal price and difference variables. Only the intercept of the third quarter tested statistically different than the first quarter. The slopes of the MP and MP^2 terms for the third and fourth quarters and the slopes of the D and D^2 terms for the third quarter tested statistically different than the first quarter. The estimated quarterly (seasonal) demand functions are presented in Table XXV.

Price, Income and Household Characteristic Effects

The overall mean monthly water (MW) consumed was 7,140 gallons and the mean marginal price (MP) was $1.78 per thousand gallons. The mean family income (INCOM) was $24,603 and the average size household was 2.8 persons. An average of 31.1 percent of nonhousehold water came from alternative sources and the mean of the difference variable was 7.6. The mean of the $\frac{\partial D}{\partial P_e}$ for the marginal price was equal to 3.4

TABLE XXV

ESTIMATED QUARTERLY DEMAND FUNCTIONS FOR WATER, SAMPLE OF OKLAHOMA RURAL HOUSEHOLDS, 1983

Regression Coefficients							
Intercept	MP	MP^2	D	D^2	INCOM	SIZH	NHALT
First and second quarters (January-June)							
11.27	- 3.95	0.564	-1.88	0.148	0.069	1.17	-0.005
Third quarter (July-September)							
12.92	-15.75	3.177	1.28	-0.040	0.069	1.17	-0.005
Fourth quarter (October-December)							
11.27	- 7.54	2.161	-1.88	0.148	0.069	1.17	-0.005

Quarterly marginal price elasticities computed at the seasonal mean of MW, MP and $\frac{\partial D}{\partial P_e}$ are the following:

First and second quarter:	-0.80
Third quarter:	-1.76
Fourth quarter:	-0.28

These results indicate that rural households are the least price elastic during the fourth quarter which corresponds to the late fall-early winter and most price elastic during the third quarter which corresponds with late summer. Rural Oklahoma households are apparently much more price elastic than urban households reported by

Howe (1982) and Billings and Agthe (1980). The price elasticities for urban water demand were -0.06 for winter and -0.43 for summer (Howe, 1982).

The income elasticity of demand is equal to 0.24. The marginal person in a rural household adds 1.17 thousand gallons to monthly water consumption.

Conclusions

Rural water system households differ by size, age composition and income. They also differ in their reasons for residing in a rural area and in their water usage patterns. The typical household is composed of approximately three members. Average household income is $24,603 a year and the typical residence is a house. Any relocation done by the household was typically done in the same county and their reason for moving to the rural water system was a preference for rural living.

Seasonal water demand functions were estimated using cross sectional data from households surveyed in 14 rural water systems. Winter, spring and fall water demands were price inelastic but summer water demand was very elastic. The estimated income elasticity was relatively small.

An investment programming model is presented in the following chapter utilizing the above quarterly (seasonal) demand information. The model determines optimal size and timing of investments and simultaneously determines quantity of water demanded and the marginal price of water.

CHAPTER V

A SEASONAL INVESTMENT PROGRAMMING MODEL FOR RURAL COMMUNITY WATER SYSTEMS

A separable programming model is developed in this chapter which operates off nonlinear seasonal household demand and nonlinear annual O&M and water purchase costs. Investment costs are characterized by a continuously declining average cost. The nonlinear functions are made linear using separable programming. The investment function is mixed integer representing a fixed investment cost plus a constant investment cost for each unit of capacity. The model developed in this chapter determines the optimal initial capacity, additions to capacity, water demand on a seasonal and yearly basis, and marginal water price on a seasonal basis. The water price is determined endogenously in the model.

The assumptions of the model are presented first and then the configuration of the model. After the above, the Kuhn-Tucker conditions are presented and discussed.

Assumptions of the Model

The assumption is made that household water demand is nonlinear and sensitive to changes in price. Rural water systems are characterized by decreasing unit costs and the objective of the systems is to maximize net benefits to members of the rural water systems. Other assumptions are:

1. Water demand in month n is a function of price in that month and no other month.

2. Capital investment costs occur as lump sums at the time of initial construction and for any additions to capacity (Myoung, 1982).

3. The capital investment costs for initial construction and any additions are a linear function of capacity, and assumed to reflect economies of scale (Myoung, 1982).

4. The O&M and water purchase costs are a nonlinear function of output and assumed to reflect economies of scale.

5. The seasonal demand functions are assumed to be a nonlinear function of quantity demanded.

6. The annual social discount rate, r, is assumed to be constant over time and equal to 4 percent.

7. Inflation effects on benefits and costs are not considered.

8. The planning horizon is assumed to be 20 years.

9. Capacity is assumed to be determined by one of the seasonal quarters of water demand.

Formulation of the Model

The objective of the programming model is to maximize the total discounted net benefits from investments in a rural community water system. The approach is to maximize the difference between the discounted sum of the benefits from water consumption and the sum of the discounted costs of the water system.

Benefit Function

The benefits associated with a given amount of consumption of water is measured by the area under the demand curve up to a specific quantity demanded. It is assumed that there is a unique price for each quantity of water consumed. The area under the seasonal demand curve can then be represented by:

$$f_n(Q_n) = 3g \int_o^{Q_m} P_m(Q)\, dQ \qquad 5.1$$

where Q_n is aggregate household water demand in season n and $P_m(Q)$ is the inverse monthly household seasonal demand function. The inverse demand function is multiplied by three to convert it to a season (quarter) and g represents the number of households in the system. The area under the demand function is then discounted to the present using:

$$\alpha_y = \frac{1}{(1+r)^y} \qquad 5.2$$

where α_y is the discount factor for year y and r is the social discount rate. The resulting benefit function for year y which appears in the objective function for each season is:

$$TB_y = \sum_{n=1}^{4} \alpha_y f_n (Q_n) \qquad 5.3$$

The monthly seasonal household demand functions estimated in Chapter IV were quadratic and of the form:

$$Q = a_1 + a_2 P + a_3 P^2 \qquad 5.4$$

where

Q = monthly water demand

P = marginal price

a_1 = intercept term and includes factors other than marginal price

a_2 = coefficient associated with P

a_3 = coefficient associated with P^2

Rearranging terms results in

$$0 = a_1 - Q + a_2 P + a_3 P^2 \qquad 5.5$$

The quadratic formula for marginal price can be written as:

$$P = \frac{a_2 \pm \sqrt{a_2^2 - 4a_3 (a_1 - Q)}}{2a_3} \qquad 5.6$$

By integrating the quadratic function of 5.6 the benefits associated with various quantities of water can be obtained. The relationship of the demand function to benefits is shown in Figure 19.

At a price of P_1 quantity demanded is $\overline{Q}_1$ and the associated benefits are represented by $\overline{B}_1$. If the price decreases to P_2 the quantity demanded is $\overline{Q}_2$ and the associated benefits are $\overline{B}_2$. When using the quadratic formula the demand function may not touch the price axis. To account for those benefits associated with a quantity less than $\overline{Q}_1$ in Figure 19 a linear approximation was obtained by determining the slope between points d and e of Figure 19 and extending it to the price axis. The result is a benefit function frontier in Figure 19 of $\overline{B}_0$a b c.

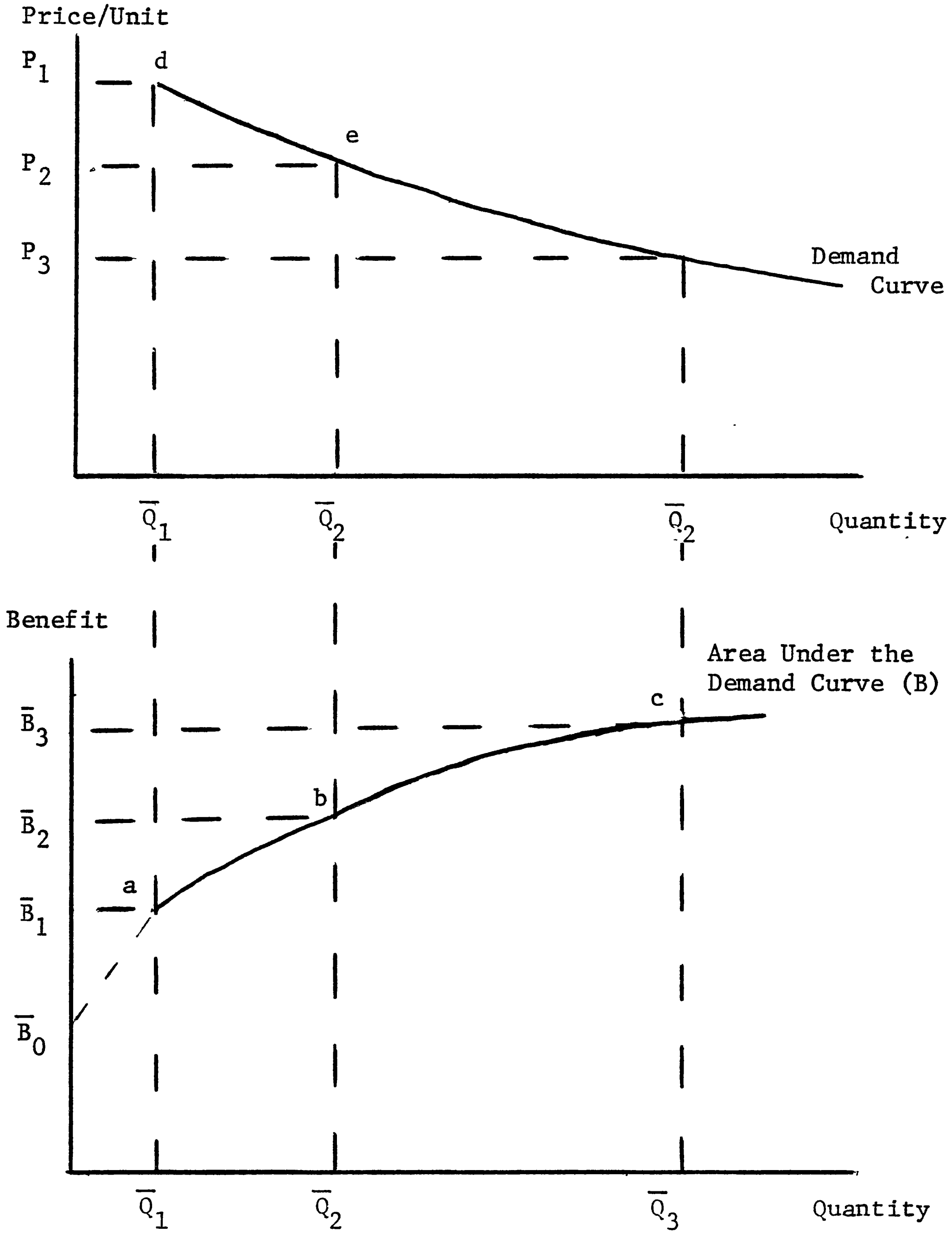


Figure 19. Estimation of the Benefit Function

Cost Functions

The model contains three cost functions which appear in the objective function: O&M, water purchase and investment. The first cost examined is the annual O&M cost. In Chapter III the average annual O&M cost function was estimated and is convex with significant economies of scale. By multiplying the average O&M cost function by Q the total cost function is determined. Integrating the marginal cost function and evaluating at various levels of Q results in alternative total costs. Annual discounted total O&M costs foir year y are represented by:

$$TO_y = {}_y\int_o^{Q_y} M_y\,(Q)\,dQ \qquad 5.7$$

where $M_y(Q_y)$ is the annual marginal cost function for O&M and TO is the present value of total annual O&M costs for year y.

Water purchase costs are derived in the same manner as O&M costs. Economies of scale are again associated with water purchase costs and are assumed to be on an annual basis. Annual discounted total costs for purchased water for year y are represented by:

$$TW_y = {}_y\int_o^{Q_y} N_y\,(Q_y)\,dQ_y \qquad 5.8$$

where $N_y(Q)$ is the annual marginal cost function for water purchases and TW_y is the present value of total annual water purchase costs for year y.

Investment costs are also assumed to reflect economies of scale. The capital cost function for the water system is denoted by $S(S_\tau)$, where S_τ is the capacity added in the $^{\tau}$th time unit.

It is assumed that additions have expected lifetimes longer than the planning horizon. Capital costs are annualized over their expected life, discounted, and summed for the years in the planning period. The total present value of the annualized capital costs appear in the objective function. Capital costs are converted to annual equivalent costs by using the capital recovery factor β:

$$\beta = \frac{r(1+r)^{m}}{(1+r)^{m-1}} \qquad 5.9$$

The social discount rate is represented by r and m is the expected lifetime of the capital investment. Capacity is allowed to be added only in the base or initial period and then every fifth year during the planning period. The total discounted capital costs over the entire planning period are:

$$TC = \sum_{\tau=0}^{T} \sum_{y=(\tau)\overline{y}}^{Y} \beta \alpha_y S_\tau \qquad 5.10$$

where

S_τ = investment function that adds capacity in building time unit τ

τ = index of building time unit, $\tau=0,1,2,\ldots,T$.

Y = length of planning period

T = number of building time units in the planning period (if planning period is 20 years and y is five years then (T=4)

$\overline{y}$ = number of years between building time units when capacity can be added (additions to capacity are allowed every $\overline{y}$ years)

Total Net Benefit

Combining equations (5.3), (5.7), (5.8) and (5.10), the complete objective function for the programming model is:

$$\text{Max.} \sum_{y=0}^{Y} (TB_y - TO_y - TW_y) - TC \qquad 5.11$$

Model Constraints

The basic constraints for the seasonal model are similar to those developed by Myoung for the annual model and are paraphrased here. The first constraint is that the quantity of water supplied, Q_{ny}, in any quarter of any year cannot exceed capacity. This constraint is represented by:

$$Q_{ny} - \sum_{\tau=0}^{G} S_\tau \leq 0 \qquad 5.12$$

where $G = \lceil y/\bar{y} \rceil$, the ceiling of $y/\bar{y}$ which indicates the number of building time units up to year y.

The second constraint deals with the allocation of water and requires that the water demanded in year y equals the water supplied in year y:

$$X_y - Q_y = 0 \qquad 5.13$$

where X_y is the quantity of water supplied in year y and Q_y is the quantity of water demanded in year y and is the summation of quarterly demand, $\sum_{n=1}^{4} Q_{ny}$.

It is assumed that capacity can only be added once in any given building time unit. The following constraints are used to obtain this:

$$S_\tau - \bar{S}Z_\tau \leq 0 \qquad 5.14$$

and

$$Z_\tau \leq 1 \qquad 5.15$$

where S is the maximum possible capacity of the water system and Z_τ is a zero-one decision variable representing the decision to add capacity in period $\tau (Z_\tau = 1)$ or not to add capacity in $\tau (Z_\tau = 0)$.

The Basic LP Model with Economic Interpretation of the Optimal Solution

The objective of the investment programming model is to maximize the present value of the net benefits accruing to a rural water system over a 20 year planning period. Five year decision time units, τ, are used instead of the annual time unit, y, to reduce the dimensions of the model. Therefore, τ takes on the values of 0, 1, 2, 3 and 4 and correspond to years 0, 5, 10, 15 and 20 for the planning period.

Investments can occur only during the five decision time units. Investment costs, when they occur, are annualized by applying the capital recovery factor assuming a four percent discount rate and 40 year life of the investment. The model assumes an initial number of households for the base year and a constant annual growth in number of households adding on to the system over the planning period. Thus demand for water shifts due to growth in family income and in number of households.

The basic linear programming model thus sums the present value of the annualized benefits and costs for the base year ($\tau = 0$) and every fifth year up to year 20 which is the last year of the planning period. The model can be stated as follows:

$$
\begin{aligned}
\text{Max. PVNB} = & \sum_{\tau s} d_\tau \quad (\overline{B}_{\tau s}W1_{\tau s} + \overline{C}_{\tau s}W2_{\tau s} + \overline{D}_{\tau s}W3_{\tau s} \\
& + \overline{E}_{\tau s}W4_{\tau s} - \overline{J}_{\tau s}W5_{\tau s} - \overline{P}_{\tau s}W6_{\tau s}) \\
& - \sum_{\tau=0}^{T} \sum_{y=(\tau)\overline{y}}^{Y} \alpha_y \, \beta(KS_\tau + fZ_\tau) \qquad 5.16
\end{aligned}
$$

subject to:

winter demand constraint (WIN)

$$\sum_s \overline{Q1}_{\tau s}W1_{\tau s} - Q1_\tau \leq 0 \qquad [a] \qquad 5.17$$

spring demand constraint (SPR)

$$\sum_s \overline{Q2}_{\tau s}W2_{\tau s} - Q2_\tau \leq 0 \qquad [b] \qquad 5.18$$

summer demand constraint (SUM)

$$\sum_s \overline{Q3}_{\tau s}W3_{\tau s} - Q3_\tau \leq 0 \qquad [c] \qquad 5.19$$

fall demand constraint (FAL)

$$\sum_s \overline{Q4}_{\tau s}W4_{\tau s} - Q4_\tau \leq 0 \qquad [d] \qquad 5.20$$

winter convexity constraint (WCON)

$$\sum_s W1_{\tau s} \leq h_\tau \qquad [e] \qquad 5.21$$

spring convexity constraint (SPCON)

$$\sum_s W2_{\tau s} < h_\tau \qquad [g] \qquad 5.22$$

summer convexity constraint (SUMCON) .

$$\sum_s W3_{\tau s} \leq h_\tau \qquad [i] \qquad 5.23$$

fall convexity constraint (FCON)

$$\sum_s W4_{\tau s} \leq h_\tau \qquad [j] \qquad 5.24$$

transfer constraint (TRANS)

$$Q1_\tau + Q2_\tau + Q3_\tau + Q4_\tau - Q_\tau = 0 \qquad [k] \qquad 5.25$$

O&M cost constraint (O&M)

$$Q_\tau - \sum_s \overline{Q5}_{\tau s} \, W5_{\tau s} \leq 0 \qquad [l] \qquad 5.26$$

O&M cost convexity constraint (OMCON)

$$\sum_s W5_{\tau s} \leq 1 \qquad [m] \qquad 5.27$$

water purchase cost constraint (WAT)

$$Q_{\tau} - \sum_{s} \overline{Q6}_{\tau s} \, W6_{\tau s} \leq 0 \qquad \text{[n]} \qquad 5.28$$

water purchase cost convexity constraint (WATCON)

$$\sum_{s} W6_{\tau s} \leq 1 \qquad \text{[o]} \qquad 5.29$$

winter capacity constraint (CAP1)

$$Q1_{\tau} - \sum_{\tau=0}^{G} S_{\tau} \leq 0 \qquad \text{[p]} \qquad 5.30$$

spring capacity constraint (CAP2)

$$Q2_{\tau} - \sum_{\tau=0}^{G} S_{\tau} \leq 0 \qquad \text{[q]} \qquad 5.31$$

summer capacity constraint (CAP3)

$$Q3_{\tau} - \sum_{\tau=0}^{G} S_{\tau} \leq 0 \qquad \text{[t]} \qquad 5.32$$

fall capacity constraint (CAP4)

$$Q4_{\tau} - \sum_{\tau=0}^{G} S_{\tau} \leq 0 \qquad \text{[u]} \qquad 5.33$$

integer constraint (INTEGER)

$$S_{\tau} - \overline{S}Z_{\tau} \leq 0 \qquad \text{[v]} \qquad 5.34$$

The Lagrangian multipliers are shown in brackets to the right of each constraint. The variables and parameters are defined below.

Definition of Variables

PVNB : present value of the net benefits for the five one year decision units

$W1_{\tau s}$: segment weight variable on winter demand and benefit function

$W2_{\tau s}$: segment weight variable on spring demand and benefit function

$W3_{\tau s}$: segment weight variable on summer demand and benefit function

$W4_{\tau s}$: segment weight variable on fall demand and benefit function

$W5_{\tau s}$: segment weight variable on annual O&M costs

$W6_{\tau s}$: segment weight variable on annual water purchase costs

$Q1_{\tau}$: quantity of water supplied in winter quarter in thousands of gallons

$Q2_{\tau}$: quantity of water supplied in spring quarter in thousands of gallons

$Q3_{\tau}$: quantity of water supplied in summer quarter in thousands of gallons

$Q4_{\tau}$: quantity of water supplied in fall quarter in thousands of gallons

Q_{τ} : annual quantity of water supplied in time unit τ in thousands of gallons

S_{τ} : capacity of water system built in time unit τ in thousands of gallons

Z_{τ} : zero-one binary variable in time unit τ

Definition of Parameters

y : year in the planning period

τ : decision time unit (τ=0,1,2,3 and 4)

s : represents linear segments on nonlinear functions

T : number of decision time units

Y : length of planning period

$\bar{y}$: number of years between decision time units when capacity can be added ($\bar{y}$=5)

G : equals $\lceil y/\bar{y} \rceil$, the ceiling of $y/\bar{y}$ and indicates the number of building time units up to y

β : capital recovery factor

α_y : discount factor for year y

d_τ : discount factor for equivalent year of α_y (i.e., for $\tau=0$, $d_\tau=\alpha_0$; for $\tau=1$, $d=\alpha_5$; etc.) in period τ

$\bar{B}_{\tau s}$: area under the demand curve for segment s of the winter demand function in dollars

$\bar{C}_{\tau s}$: area under the demand curve for segment s of the spring demand function in dollars

$\bar{D}_{\tau s}$: area under the demand curve for segment s of the summer demand function in dollars

$\bar{E}_{\tau s}$: area under the demand curve for segment s of the fall demand function in dollars

$\bar{J}_{\tau s}$: area under the marginal cost curve for operation and maintenance for segement s in dollars

$\bar{P}_{\tau s}$: area under the marginal cost curve for water purchase for segment s in dollars

$\bar{Q}1_{\tau s}$: amount of water consumed at segment s of the winter demand function in thousands of gallons

$\bar{Q}2_{\tau s}$: amount of water consumed at segment s of the spring demand function in thousands of gallons

$\bar{Q}3_{\tau s}$: amount of water consumed at segment s of the summer demand function in thousands of gallons

$\bar{Q}4_{\tau s}$: amount of water consumed at segment s of the fall demand function in thousands of gallons

$\overline{Q5}_{\tau s}$: amount of water supplied on an annual basis for O&M costs at segment s

$\overline{Q6}_{\tau s}$: amount of water supplied on an annual basis for water purchase costs at segment s

h_{τ} : factor for expanding monthly household water demand to seasonal aggregate demand for time period τ

g_{τ} : number of households in time period τ

f : fixed investment cost in dollars

K : variable investment cost in dollars per thousand gallons

$\overline{S}$: maximum possible water system capacity in thousands of gallons

The Kuhn-Tucker conditions provide the necessary and sufficient conditions for determining an optimal solution. From the LP model the Lagrangian equation is as follows:

$$
\begin{aligned}
& L(W1,W2,W3,W4,W5,W6,Q1,Q2,Q3,Q4,Q,S,Z) = \\
& \sum_{\tau s} d_{\tau}(\bar{B}_{\tau s}W1_{\tau s} + \bar{C}_{\tau s}WZ_{\tau s} + \bar{D}_{s}W3_{\tau s} + \bar{E}_{\tau s}\,W4_{\tau s} - \\
& \bar{J}_{\tau s}W5_{\tau s} - \bar{P}_{s}W6_{\tau s}) - \sum_{\tau=0}^{T}\ \sum_{y=(\tau)\bar{y}}^{Y} \alpha_{y}\,(KS_{\tau} + fZ_{\tau}) \\
& -a(-Q1_{\tau} + \sum_{s} \bar{Q}1_{\tau s}W1_{\tau s}) \\
& -b(-Q2_{\tau} + \sum_{s} \bar{Q}2_{\tau s}W2_{\tau s}) \\
& -c(-Q3_{\tau} + \sum_{s} \bar{Q}3_{\tau s}W3_{\tau s}) \\
& -d(-Q4_{\tau} + \sum_{s} \bar{Q}4_{\tau s}W4_{\tau s}) \\
& -e(\sum_{s} W1_{\tau s} \ -h_{\tau}) \\
& -g(\sum_{s} W2_{\tau s} \ -h_{\tau}) \\
& -i(\sum_{s} W3_{\tau s} \ -h_{\tau}) \\
& -j(\sum_{s} W4_{\tau s} \ -h_{\tau}) \\
& -k(Q1_{\tau} + Q2_{\tau} + Q3_{\tau} + Q4_{\tau} - Q_{\tau}) \\
& -l(Q_{\tau} - \sum_{s} \bar{Q}5_{\tau s}W5_{\tau s}) \\
& -m(\sum_{s} W5_{\tau s} - 1) \\
& -n(Q_{\tau} - \sum_{s}\bar{Q}6_{\tau s}W6_{\tau s}) \\
& -o(\sum_{s} W6_{\tau s} - 1) \\
& -p(Q1_{\tau} - \sum_{\tau=0}^{G} S_{\tau}) \\
& -q(Q2_{\tau} - \sum_{\tau=0}^{G} S_{\tau}) \\
& -t(Q3_{\tau} - \sum_{\tau=0}^{G} S_{\tau}) \\
& -u(Q4_{\tau} - \sum_{\tau=0}^{G} S_{\tau}) \\
& -v(S_{\tau} - \bar{S}Z_{\tau}) \qquad 5.35
\end{aligned}
$$

Results of the Kuhn-Tucker conditions are provided in Appendix F. These conditions provide the Lagrangian solutions. Economic interpretation of these solutions are given in the following equations. It can be shown that

$$a = \frac{d_\tau \overline{B}_{\tau s}}{\Sigma \overline{Q}1_{\tau s}} \qquad 5.36$$

where $d_\tau \overline{B}_{\tau s}$ is equal to the discounted area under the demand curve for a particular segment of the winter demand and $\sum_s \overline{Q}1_{\tau s}$ is the amount of water supplied during the winter quarter. The term can be interpreted as the marginal benefit which accrues for each additional unit of water consumed. The terms b, c and d have the same interpretation as a except they are for the spring, summer and fall quarters respectively.

The term 1 is equal to:

$$1 = \frac{d_\tau \overline{J}_{\tau s}}{\sum_s \overline{Q}5_{\tau s}} \qquad 5.37$$

Where $d_\tau \overline{J}_{\tau s}$ is equal to the total marginal cost of O&M for segement s and $\sum_s \overline{Q}5_{\tau s}$ is the annual amount of water supplied. The Lagrangian g is then equal to the marginal cost of O&M for supplying an additional thousand gallons of water. Similarly, it can be shown that n is equal to the marginal cost of water purchases for supplying an additional thousand gallons of water.

The Lagrangian multiplier k is associated with the transfer of water from a quarterly basis to an annual basis. Beneke (1973) notes that the Lagrangian multiplier associated with a transfer has no meaningful economic interpretation since there is no cost associated with the transfer.

The Lagrangian multipliers p, q, t and u are associated with the capacity of the system. Since capacity will be constrained by only one of the four seasonal water demands, only one of the Lagrangian multipliers will be a positive value. The remaining three will be zero. It is expected that capacity will be constrained in the summer quarter so the values of p, q and u will be zero. The Lagrangian multiplier for t is:

$$t = \beta K \sum_{\tau=0}^{T} \sum_{y=(\tau)\bar{y}}^{S} \alpha_y + \left(\frac{\beta f}{\bar{S}}\right) \sum_{\tau=0}^{T} \sum_{y=(\tau)y}^{Y} \alpha_y \qquad 5.38$$

returns from capacity built in τ	discounted variable cost of constructing the capacity in τ	discounted fixed charge per unit of maximum scale of capacity

The results of the model are contained in Chapter VI along with the implications of alternative pricing strategies.

CHAPTER VI

DESIGNING A RATE STRUCTURE FOR RURAL WATER SYSTEMS

Introduction

In the preceeding chapter a mathematical programming model incorporating separable programming was developed so that nonlinear seasonal household demand functions and nonlinear cost functions could be used in determining optimal size and timing of water system investments under conditions of maximizing present value of net benefits. This chapter deals with the results of the model using scenarios typical of rural water systems in Oklahoma. Using the results of one of the scenarios principles of designing a resource efficient water rate structure are developed and applied.

Scenario for Typical Rural Water System

The linear programming model developed in Chapter V was run assuming 412 residential taps in the system at initiation. It was assumed that the hypothetical system grew in number of residential taps at an annual rate of four percent.

A constant discount rate of 4 percent was used for the 20 year planning period. Decision units were every five years including a base year in time period zero. The base year was 1983 and all data were adjusted to prices for that year. The expected useful life of investments for increasing capacity was 40 years.

The estimated cost functions for water purchase, operation and maintenance, and investment were taken from Chapter III. Density of the system was assumed to be eight residential taps per mile.

The estimated monthly seasonal household demand functions were taken from Chapter IV. The initial income level was assumed to be $24,795 and to increase at an annual rate of two percent. The size of the household was assumed to be three individuals and to not change over time. The amount of nonhousehold alternative water was assumed to be 30 percent. The difference variable in the demand function was assumed at a value of 7.45. It was also assumed that each estimated monthly seasonal demand function represented the other months in the respective season.

Results of the Investment Programming Model

Using the above scenario the present value of net benefits were $119,942. The system added capacity in the first period only and equalled 13,284,840 gallons per quarter. Capacity was determined on the basis of the summer constraint for the scenario.

The aggregate water demand by season and year is contained in Table XXVI. Excess capacity exists until 1993 when summer hits the capacity constraint. In both 1998 and 2003 the spring-fall and summer quarter hit the capacity constraint.

The seasonal equilibrium water price (marginal price) and monthly quantity of water demanded per household is contained in Table XXVII.

TABLE XXVI

PROGRAMMING RESULTS FOR AGGREGATE WATER DEMAND BY SEASON AND YEAR

Year	Seasonal Quarter	Number of Households	Quantity of Water Demanded by Season & Year (gallons)
1983	Winter	412	4,400,160
	Spring-Fall (2)	412	13,546,560
	Summer	412	8,701,440
	Total		26,648,160
1988	Winter	501	4,437,850
	Spring-Fall (2)	501	16,623,180
	Summer	501	10,521,000
	Total		31,582,030
1993	Winter	609	6,668,550
	Spring-Fall (2)	609	21,412,440
	Summer	609	13,284,840
	Total		41,365,830
1998	Winter	743	9,450,960
	Spring-Fall (2)	743	26,569,680
	Summer	743	13,284,840
	Total		49,305,480
2003	Winter	902	10,309,860
	Spring-Fall (2)	902	26,569,680
	Summer	902	13,284,840
	Total		50,164,380

TABLE XXVII

PROGRAMMING RESULTS FOR SEASONAL MONTHLY HOUSEHOLD WATER DEMAND, PRICE AND WATER BILL

Year	Seasonal Quarter	Monthly Quantity (gallons)	Marginal Price ($ per 1,000 gallons)	Water Bill ($)
1983	Winter	3,560	2.20	7.83
	Spring-Fall	5,480	2.21	12.11
	Summer	7,400	2.25	16.65
1988	Winter	2,950	2.28	6.73
	Spring-Fall	5,530	2.30	12.71
	Summer	7,000	2.31	16.17
1993	Winter	3,650	2.22	8.10
	Spring-Fall	5,860	2.22	13.01
	Summer	7,271	2.34	17.02
1998	Winter	4,240	1.79	7.59
	Spring-Fall	5,960	2.31	13.77
	Summer	5,960	2.67	15.91
2003	Winter	3,810	2.30	8.76
	Spring-Fall	4,910	2.86	14.04
	Summer	4,910	3.51	17.24

Also contained in Table XXVII are the household water bills per month by season if water was charged at the marginal price per thousand gallons.

As expected, the quantity demanded was greatest during the summer months and lowest during the winter months. The marginal water prices by season by year should be similar and equal to the annual marginal cost until the system is constrained by capacity. The slight differences for 1983 and 1988 can be explained by the segmentation of the demand and cost functions using separable programming and rounding. In comparing the Spring-Fall quantity demanded and water price for the years 1983 and 1988, it is seen that the price increased with increased water usage. The explanation for this is that income increased from 1983 at a two percent annual growth rate which resulted in an upward shift of the demand function for 1988. The demand function for 1988 thus lies above the household demand function for 1983. In period three, or 1993, the summer price rises relative to the other seasons. The cause for this is that price begins to act as a rationing instrument since water demanded now equals the capacity of the system.

The problem attributed to marginal cost pricing under conditions of decreasing unit cost is that losses occur. In order to determine the losses average cost must be computed. Average O&M and water purchase costs are the same for each season since they are computed from the annual cost functions estimated in Chapter III. The average O&M and water purchase costs are contained in Table XXVIII. Average O&M cost decreases slightly as quantity of water increases. For the system, O&M cost decreases from $1.74 per thousand for 26,698,160

TABLE XXVIII

AVERAGE COSTS COMPUTED FROM PROGRAMMING RESULTS (PER 1,000 GALLONS)

Year	Average O&M Cost ($)	Average Water Purchase Cost ($)	Total Average Variable Costs (O&M and Water Purchase) ($)	Average Annualized Investment Cost ($)	Total Average Fixed and Variable Cost ($)
1983	1.74	0.83	2.57	1.61	4.18
1988	1.73	0.79	2.52	1.36	3.88
1993	1.71	0.71	2.42	1.04	3.46
1998	1.70	0.65	2.35	0.87	3.22
2003	1.69	0.64	2.33	0.85	3.18

gallons in 1983 to $1.69 per thousand for 50,164,380 gallons in 2003. Average water purchase cost decreases as quantity of water increases from $0.83 per thousand in 1983 to $0.64 per thousand in 2003. Water purchase cost is estimated from the results of Table XIV in Chapter III. The time variable, however, was held constant at the 1983 value.

Annualized investment cost was calculated as an average fixed cost per 1,000 gallons of water and is presented in Table XXVIII. Since this annualized investment cost is spread over more gallons for succeeding time periods, the average fixed cost decreases. The values ranged from $1.61 in 1983 to $0.85 in 2003 per thousand gallons for the system. Total average costs, fixed and variable, range from $4.18 in 1983 per thousand gallons to $3.18 per thousand gallons in 2003. Costs were also put on a household basis and monthly total revenue and cost results are presented in Table XXIX. The relatively high fixed investment cost per household in the early years is because there are fewer households to distribute this cost over. Revenue is computed using the marginal price of water and total cost is equal to total variable cost plus monthly household fixed investment cost.

All cash flows are negative with the exception of summer in the year 2003. Cash flows for the summer months are the least negative for the years 1993, 1998 and 2003. This can be explained by: (1) fixed investment costs are spread out over more households during the later periods; (2) more economies of scale are realized in variable cost during later periods when total volume of water increases; and (3) marginal water price increases for summer months beginning in 1993 and in spring-fall months beginning in 1998. The winter cash flow is the least negative season for years 1983 and 1988 and is related to

TABLE XXIX

CASH FLOW PER HOUSEHOLD PER SEASON PER MONTH COMPUTED FROM PROGRAMMING RESULTS

Year	Number of Households	Season	Total Revenue ($)	Total Variable Cost ($)	Fixed Cost of Investment Per Household ($)	Total Cost ($)	Cash Flow ($)
1983	412	Winter	7.83	9.15	8.66	17.81	-9.98
	412	Spring-Fall	12.11	14.08	8.66	22.74	-10.63
	412	Summer	16.65	19.02	8.66	27.68	-11.03
1988	501	Winter	6.73	7.44	7.12	14.56	-7.83
	501	Spring-Fall	12.72	13.94	7.12	21.06	-8.34
	501	Summer	16.17	17.64	7.12	24.76	-8.59
1993	609	Winter	8.10	8.84	5.86	14.70	-6.60
	609	Spring-Fall	13.01	14.18	5.86	20.04	-7.03
	609	Summer	17.02	17.60	5.86	23.46	-6.44
1998	743	Winter	7.59	9.97	4.80	14.77	-7.18
	743	Spring-Fall	13.77	14.01	4.80	18.81	-5.04
	743	Summer	15.91	14.01	4.80	18.81	-2.90
2003	902	Winter	8.76	8.88	3.96	12.84	-4.08
	902	Spring-Fall	14.04	11.44	3.96	15.40	-1.36
	902	Summer	17.24	11.44	3.96	15.40	1.84

low volume use. The summer cash flow is the least negative season for years 1993, 1998 and 2003 and is related to higher marginal prices.

The decrease in fixed cost of investment (annualized) per household in later years of the planning period can be explained by the increasing number of households. As mentioned earlier there is excess capacity in the early part of the planning period. The implications of this are that the original members of the water system must bear a higher proportion of fixed costs of investment in the beginning so that capacity will be available for households hooking-up to the system in later periods.

Marginal cost pricing of resources leads to optimal allocation of resources and thus should be an important factor in designing rate structures. However, marginal cost pricing results in losses under decreasing unit cost conditions. The next section covers pricing schedules currently used in rural water systems and examines alternative pricing strategies based on criteria important to rural water systems including resource use efficiency.

Current Pricing Strategies

Of the responding rural water systems, 58 provided their pricing schedules which are contained in Appendix D. The highest service charge was $17.00 for zero gallons of water. The lowest service charge was $2.00 for the first 1,000 gallons. Of the systems responding, 21 had a two tier pricing schedule which incorporated a service charge and then a flat rate for each additional thousand gallons. Thirty-six systems had more than two tiers in a decreasing block rate structure and one system had an increasing block rate structure. The largest number of tiers per pricing schedule was 14. The mean number of tiers was 3.8.

The longest a current rate schedule has been in effect of the sampled rural water systems was since 1969. The shortest period of time was 1984 with the mean being 1981. In conversations with rural water system managers the surveyor found little acceptance for seasonal pricing strategies and that systems do not like to change their rate structure very often.

The household in the survey with the largest amount of water purchased was 79,000 gallons per month (over a three month season) for a monthly water bill of $90.06. The largest monthly water bill from the household survey was $110 for 71,000 gallons. The smallest water bill was $6.24 for 1,650 gallons. The smallest amount of water purchased was zero gallons at a service cost of $11.00.

The above indicates considerable diversity in pricing schedules. Various types of rate structures were discussed in Chapter II. Figure 20 shows an assumed rate structure in the form of a decreasing block rate with three different demand functions: D1, D2 and D3. Assume that D1, D2 and D3 represent different household demands for water in a particular month. From Figure 20 it is shown that household D1 pays a marginal price of P_2 for quantity Q_1. Household D2 pays a marginal price of P_3 for Q_2 and household D3 pays a marginal price of P_4 for Q_3. Price discrimination is occurring since all households have a different marginal price. Similarly, if the same

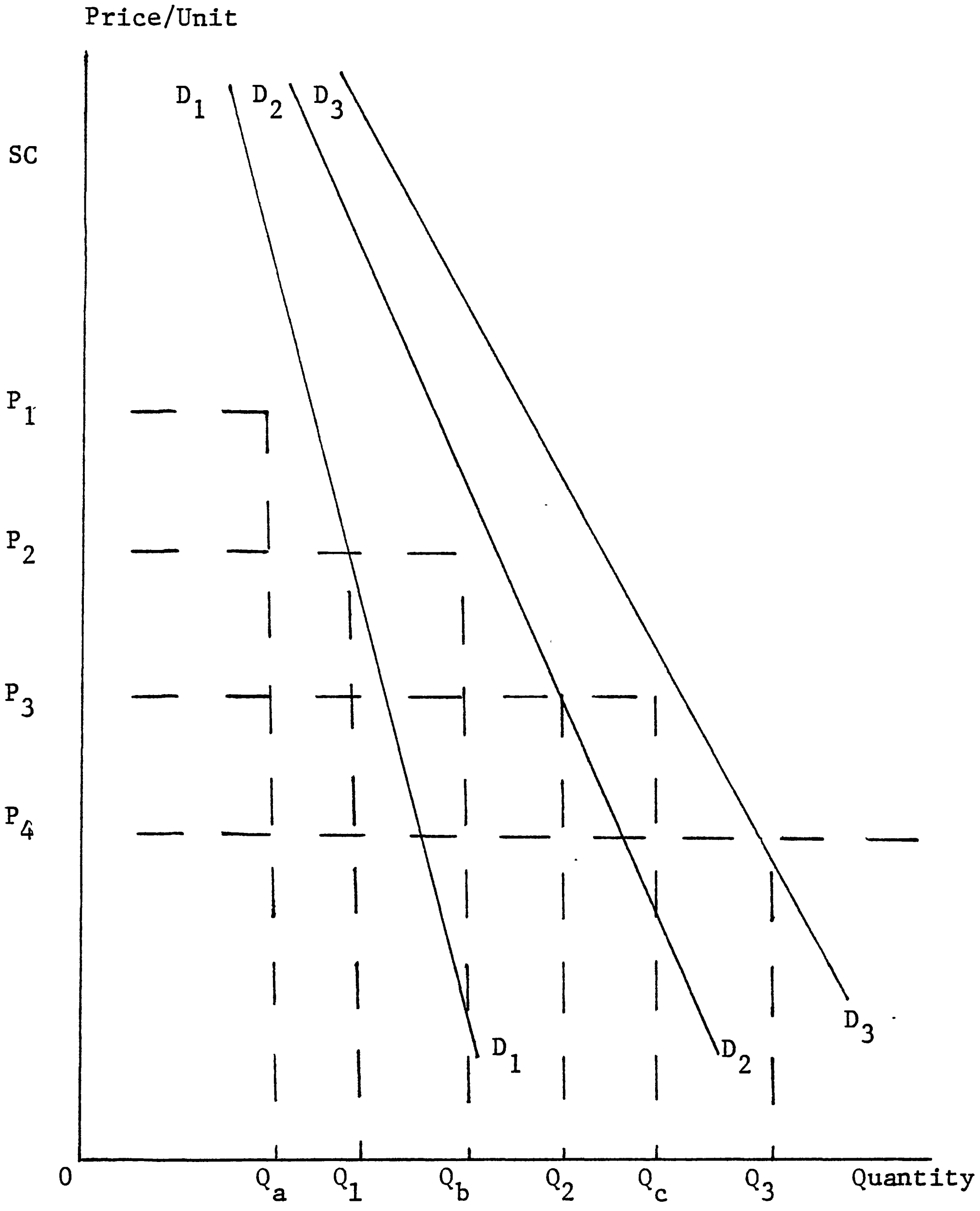


Figure 20. Price Discrimination Using a Decreasing Block Rate

household was represented in Figure 20 but with three different seasonal demand functions, the marginal price for each season would be different.

With an increasing block rate the type of price discrimination would be reversed. The greater the number of tiers that occur in a pricing strategy which effect different classes of customers the greater the degree of price discrimination.

Principles of Water Rate Design

From the preceding analyses some principles of water rate design can be identified. For purposes of analysis, demand functions are assumed for the representative consumer for each season. This can lead to the result that low volume consumers (i.e. see Figure 20) will face a different marginal price than the representative consumer. It is further assumed that consumers (and water district managers) prefer rather stable rate schedules. Therefore, the same rate structure holds for all seasons and rate changes are limited to the five year planning units. The principles are listed below and discussed:

1. Total revenue must cover total cost on an annual basis.

2. The marginal unit of water consumed should be priced equal to the marginal cost of providing that unit of water and for each household.

3. At least two pricing tiers are needed to assure marginal cost pricing and sufficient total revenue to cover total cost.

4. Fixed costs, including investment and operation and maintenance, should be allocated to households on a basis independent of quantity of water consumed.

5. Just prior to hitting the capacity constraint the system should give consumers a signal to begin conserving water by introducing an increasing block rate structure.

The basic source of revenue for rural water systems is charges made for water supplied to each household. As mentioned throughout this study, marginal cost pricing represents the most efficient use of society's resources but under conditions of decreasing unit costs it results in total revenue less than total cost. If a system fails to cover costs in the long run the result is failure of the system. Two possible solutions exist to cover revenue shortfalls. First, price discrimination can be used to extract higher portions of consumers surplus and thus increase revenue. Since rural water systems are able to administer prices, extracting part of consumer's surplus is possible through price discrimination.

Second, public subsidies can be used to reduce revenue shortfalls. Subsidies and grants from FmHA have been used to assist low income rural areas to finance water systems. Since public subsidies and grants have not been used to influence the underlying cost structure of rural water systems in the programming model, the fact that such transfers may be used to cover revenue shortfalls will not affect the optimal solutions. Subsidies and grants are proposed here only to reduce revenue shortfalls or negative cash flows.

The marginal unit of water should be priced equal to the marginal cost of providing that unit of water and equal to the marginal benefit derived from its consumption. Figure 21 shows the principles of marginal cost pricing derived for the system (Graph B) and applied to the household (Graph A). Marginal price for the system is P_3 and

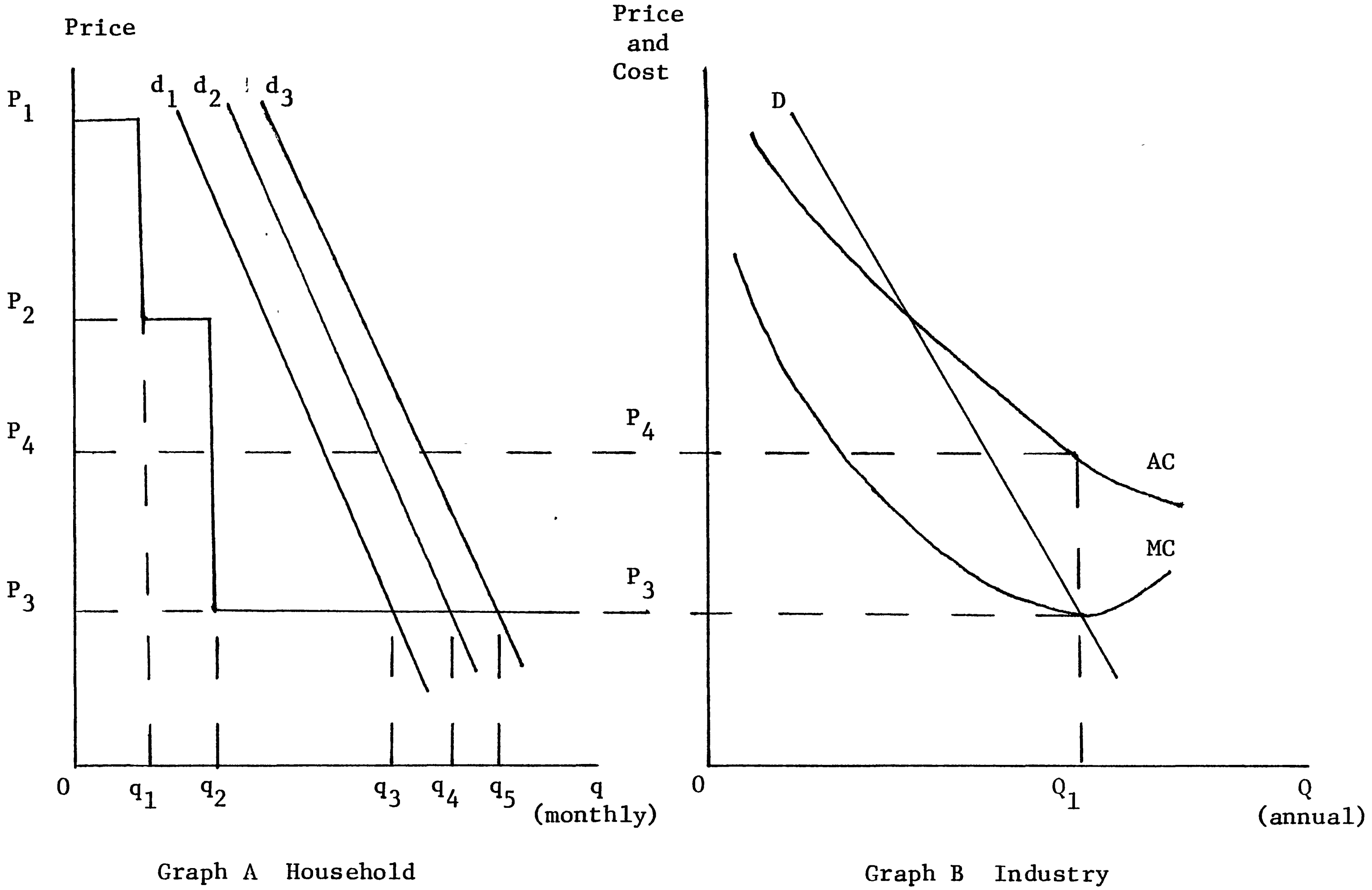


Figure 21. Pricing of Water Resources

represents the marginal cost of providing the annual quantity of water Q_1. D represents aggregate demand for water and is the summation of monthly household demand for all households. The assumption here is that the marginal cost of supplying water to all households and during any month of the year is the same and equal to P_3.

Monthly household demand for water is represented in Graph A of Figure 21. Seasonal demand is distinguished by d_1 (winter), d_2 (spring and fall) and d_3 (summer). Marginal price P_3 indicates that q_3 quantity of water is demanded in winter, q_4 quantity in spring and fall and q_5 quantity in summer.

Marginal cost pricing of water results in revenue shortfalls as shown in Figure 21 since the marginal cost of Q_1 is equal to P_3 and average cost is higher and equal to P_4. Part of household demand for water must be priced at a rate higher than average cost of water if the marginal units of water are to be priced at marginal cost and if sufficient total revenue is to be generated to cover total cost. This means there must be at least two price tiers in the rate schedule. There is an infinite number of possible water rate schedules that can be derived from Figure 21. A three price tier schedule is shown in Graph A. P_1 can represent the average cost of the first q_1 gallons of water. This could also represent a monthly service charge equal to P_1q_1 and entitles the household to consume up to q_1 gallons of water. The second price tier is P_2 per unit of water for the quantity (q_2-q_1). Any quantity of water over q_2 is priced at the marginal price P_3 and represents the third price tier.

If the marginal units of water consumed are priced at marginal cost and if the same rate schedule is to be used for all seasons, then any price tier must be less than the average revenue derived from household demand d_1. This is the same as saying that any price tier other than P_3 must not touch the household demand d_1 otherwise the marginal price for d_1 becomes that price tier rather than P_3. This restriction need not hold if different rate schedules are used for different seasons.

When a system is built investment costs are incurred. Each household connected to the system is reserved a capacity within the system whether or not it consumes any water. Households should be charged for the investment costs associated with the reserved capacity. In addition, certain costs of operation such as meter reading, billing and customer service is required for each household regardless of the amount of water consumed. Therefore, these fixed costs of operation should be charged on a time period basis rather than on the basis of amount of water consumed.

Fixed costs are generally assessed by means of a monthly service charge and should be sufficient to cover amortized investment costs and fixed costs of operation and maintenance. Generally, a minimum amount of water is granted each month to the household in association with the service charge. This minimum amount of water should be low enough so that it does not become the total amount of water consumed by the household. The primary purpose of the monthly service charge is to recover investment cost and fixed costs of operation.

Maximizing present worth of net benefits over a planning period and under conditions of growth in number of households and economies of scale in water supply leads to inequities among households in assessing fixed costs. The mathematical programming model essentially optimizes upon excess capacity. Given the conditions of growth and economies of scale, the model determines the timing of investment and size of facility. Under positive discount rates, a system builds more capacity than the initial number of households require. Excess capacity is reserved for latecomers. The question becomes, how much of the fixed costs should be assessed initial members versus latecomers? Since investment costs are generally amortized over the life of the investment, there are fewer households to distribute annual amortized costs over during initial periods than later periods when more households are added. An equity problem clearly emerges.

Several factors should be considered in addressing the issue of assessing fixed investment costs:

1. All households benefit from taking advantage of economies of scale and building excess capacity for future growth.

2. Early rural water systems and initial members in those systems have generally benefited from public subsidies and protection from competition.

3. Expected growth in number of households wanting to connect to a system is uncertain and thus the optimum excess capacity is uncertain.

One method of assessing fixed investment costs is to combine an initiation or hook-up fee with monthly service charges. The initiation fee can then be adjusted upwards through time as households are added and thus be assessed costs of holding the excess capacity.

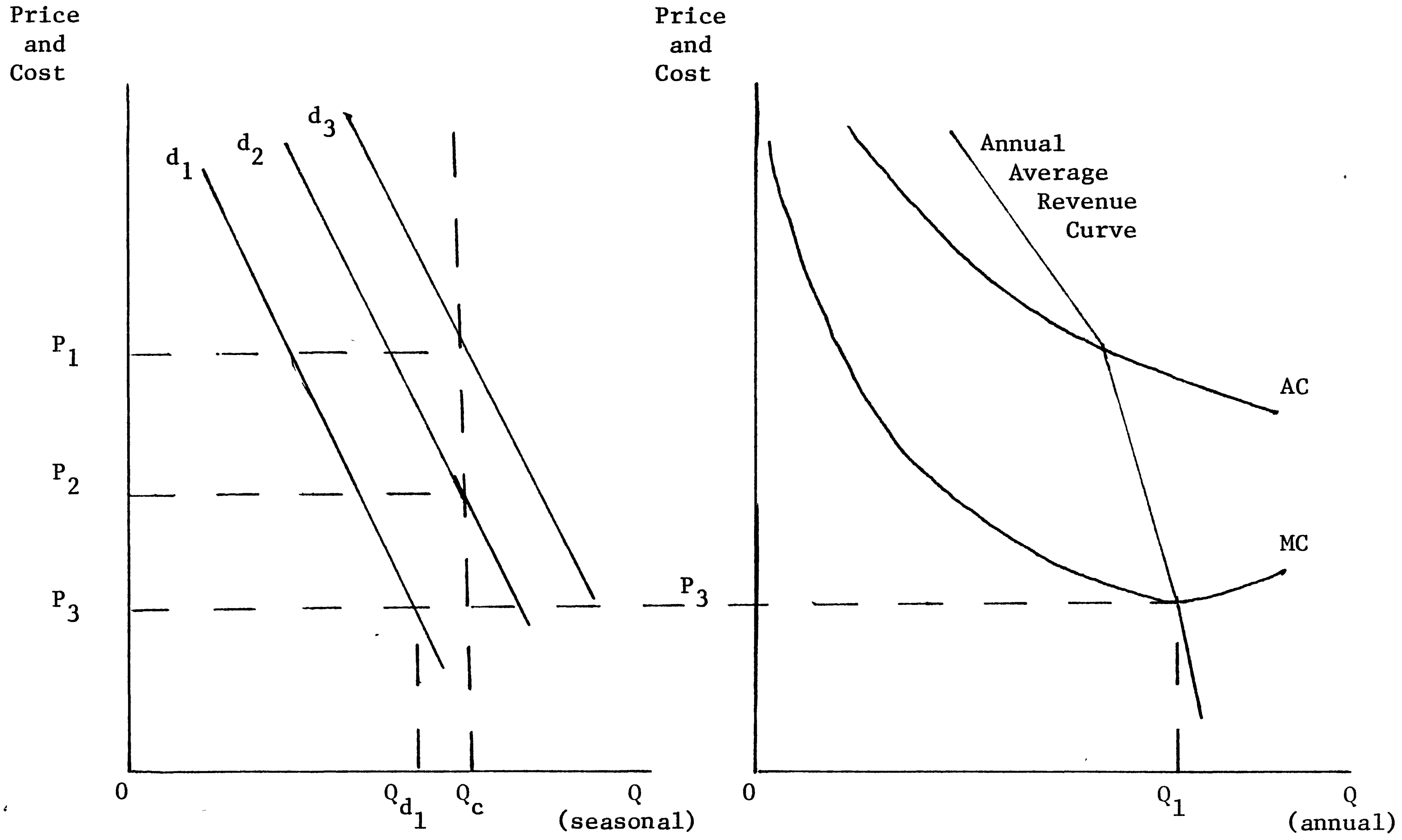
The need for an increasing block rate structure is evident from the increasing marginal prices for later time units as shown in Table XXVII. The programming results would indicate that it is not optimum to add additional capacity by the year 2003. However, growth in demand from an increased number of households and increased income is pressing on the capacity constraint and thus increasing the marginal price. This result is shown in Figure 22.

Graph B of Figure 22 shows the aggregate annual average revenue and the annual MC and AC curves. The aggregate annual average revenue is actually the summation of the seasonal demands but with the results of seasonal capacity constraints. Graph A shows aggregate seasonal demand and is the summation of individual seasonal household demands. Q_c in Graph A is the seasonal capacity constraint and is responsible for forcing the marginal price from P_3 up to P_2 for seasonal demand d_2 and up to P_1 for seasonal demand d_3.

A decreasing and then increasing block rate structure could be designed to send the appropriate signals to individual households. A service charge could be the first price tier. A second price tier could be at price P_3 so that this becomes the marginal price for season d_1. A third price their could be P_2 so that it becomes the marginal price for season d_2. The last price tier could be P_1 and this becomes the marginal price for the most constrained season d_3.

Water Rate Structures Assuming the Typical Rural Water System Scenario

Two rate structures were developed from an infinite number of possibilities with one rate structure incorporating an initial or



Graph A System-Seasonal

Graph B System-Annual

Figure 22. Marginal Price Under Seasonal Capacity Constraint

hook-up fee. Results of the programming model were used for examining the rate structures. The yearly marginal cost is equal to the short run marginal cost for operations and maintenance and water purchase as well as the long run marginal cost of investment.

One tier of the proposed rate structure must be equal to the marginal cost. Another tier must be at least equal to the fixed cost of investment allocated on a per household basis. As the number of households increase with time the service charge will decrease since the costs are spread over more households.

In 1993 the capacity constraint begins to take effect and the marginal price of water for the summer season increases. In order to signal the reduction in excess capacity these increases need to be incorporated into the pricing strategy.

Water Rate Structure Without Connection Fee

A water rate structure incorporating marginal cost pricing as one tier is presented in this section. The proposed rate structure incorporates a service charge to cover the fixed cost of investment on a household basis plus an additional amount to cover the costs of billing and meter reading. The proposed rate structure is presented in Table XXX. For the first two periods a three tier rate structure is used with the last tier equal to the marginal cost. Since the fixed cost of investment is spread over more households in each period the service charge decreases in later periods. The intramarginal tier was set at $3.00 and is only slightly less than the total average cost (Table XXVIII).

TABLE XXX

PROPOSED RATE STRUCTURE WITHOUT CONNECTION FEE FOR THE ASSUMED TYPICAL RURAL WATER SYSTEM SCENARIO

Year	Rate Structure	
1983	First 1,000 gallons	$12.00 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Remainder	Marginal cost per thousand gallons ($2.30)
1988	First 1,000 gallons	$10.50 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Remainder	Marginal cost per thousand gallons ($2.22)
1993	First 1,000 gallons	$9.00 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Next 4,000 gallons	Marginal cost per thousand gallons ($2.07)
	Remainder	Summer marginal price per thousand gallons ($2.34)
1998	First 1,000 gallons	$7.50 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Next 3,000 gallons	Marginal cost per thousand gallons ($2.04)
	Remainder	Summer marginal price per thousand gallons ($2.67)
2003	First 1,000 gallons	$5.00 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Next 2,000 gallons	Marginal cost per thousand gallons ($2.04)
	Remainder	Summer marginal price per thousand gallons ($3.51)

For the last three periods a four tier pricing strategy was used. The service charge continues to decrease from earlier periods, but now the marginal cost is used as an intramarginal tier. The final tier is equal to the summer marginal price. The results of total water costs per household with water charges are contained in Table XXXI. Cash flows are close to zero indicating that total revenue is close to total costs.

Water Rate Structure With Connection Fee

Rural water systems often charge a connection fee for new customers. Original system members finance initial investment including excess capacity to allow for system growth. In order to distribute some of the excess capacity cost to new household connections the following method is used. A one time connection fee of $500 is charged to each member. This per household cost is charged to the initial users as well as those who come on to the system at a later date. Customers who connect at a later time pay the original one time cost plus an interest rate charge for reserving capacity. The later in time a household connects to the system the higher the connection fee will be. For the proposed rate structure the interest rate is four percent compounded annually.

The proposed rate structure using a connection fee is the same as the one without a connection fee except the service charge was reduced by a third. The proposed rate structure is contained in Table XXXII. The connection fee acts as a form of revenue for the rural water system and is annualized over 40 years at a four percent discount

TABLE XXXI

CASH FLOW PER HOUSEHOLD FOR PROPOSED RATE STRUCTURE WITHOUT CONNECTION FEE

Year	Seasonal Quarter	Monthly Quantity (gallons)	Total Cost ($)	Water Charges ($)	Net Cash Flow ($)
1983	Winter	3,560	17.81	18.59	0.78
	Spring-Fall	5,480	22.74	23.00	0.26
	Summer	7,400	27.68	27.42	-0.26
1988	Winter	2,950	14.56	15.61	1.05
	Spring-Fall	5,530	21.06	21.34	0.28
	Summer	7,000	24.76	24.60	-0.16
1993	Winter	3,650	14.70	15.42	0.72
	Spring-Fall	5,860	20.04	19.99	-0.05
	Summer	7,271	23.46	23.25	-0.21
1998	Winter	4,240	14.77	15.07	0.30
	Spring-Fall	5,960	18.81	19.18	0.37
	Summer	5,960	18.81	19.18	0.37
2003	Winter	3,810	12.84	11.69	-1.15
	Spring-Fall	4,910	15.40	15.27	-0.13
	Summer	4,910	15.40	15.27	-0.13

TABLE XXXII

PROPOSED RATE STRUCTURE WITH CONNECTION FEE FOR THE ASSUMED TYPICAL RURAL WATER SYSTEM SCENARIO

Year	Rate Structure	
1983	First 1,000 gallons	$8.00 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Remainder	Marginal cost per thousand gallons ($2.30)
1988	First 1,000 gallons	$7.00 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Remainder	Marginal cost per thousand gallons ($2.22)
1993	First 1,000 gallons	$6.00 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Next 4,000 gallons	Marginal cost per thousand gallons ($2.07)
	Remainder	Summer marginal price per thousand gallons ($2.34)
1998	First 1,000 gallons	$5.00 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Next 3,000 gallons	Marginal cost per thousand gallons ($2.04)
	Remainder	Summer marginal price per thousand gallons ($2.67)
2003	First 1,000 gallons	$3.34 service charge
	Next 1,000 gallons	$3.00 per thousand gallons
	Next 2,000 gallons	Marginal cost per thousand gallons ($2.04)
	Remainder	Summer marginal price per thousand gallons ($3.51)

rate. The original 412 members paying a $500 connection fee contribute an equivalent annual revenue of $10,408 for the 20 year planning period. The 89 members added in the fifth year pay a connection fee of $608. The aggregate amount is annualized over 35 years and this annual revenue is added to the amount of the original members. The financial situation for the rural water system using a connection fee is contained in Table XXXIII. The net cash flow shows a negative amount in early years and a positive amount in later years of the planning period.

Conclusion

Results of the investment programming model were presented assuming conditions for a typical rural water system in Oklahoma. The scenario included an initial system size of 412 households with an annual growth rate of four percent in number of households. The present value of net benefits to the system equalled $119,942. Capacity was added only in the first period and equalled 13,284,840 gallons per quarter.

Results of the model with marginal cost pricing of all water show the system operates at a negative cash flow for the 20 year planning period. Principles of water rate design were developed and applied to the programming solution using price discrimination and thus capturing more of consumers surplus. The results give positive cash flows for the 20 year planning period and allow for marginal cost pricing of the marginal units of water consumed.

TABLE XXXIII

CASH FLOW FOR THE SYSTEM FOR PROPOSED RATE STRUCTURE WITH CONNECTON FEE

Year	Number of Households	Total Annual Cost ($)	Annualized Value of Connection Fees ($)	Water Charges ($)	Net Cash Flow ($)
1983	412	111,389	10,408	94,319	-6,662
1988	501	122,538	13,309	103,542	-5,687
1993	609	143,126	17,932	121,404	-3,790
1998	743	158,764	25,656	139,558	6,450
2003	902	159,523	38,554	137,708	16,739

CHAPTER VII

SUMMARY RESULTS, POLICY IMPLICATIONS AND CONCLUSIONS

Introduction

Rural water systems are characterized as decreasing cost industries. Economic theory stresses marginal cost pricing of goods and services for efficient allocation of resources. However, in a decreasing cost industry marginal cost pricing will result in negative cash flows for the industry. This study develops and applies principles of water rate design for rural water systems which incorporate marginal cost pricing yet results in positive cash flows.

A multiperiod programming model was developed and used to plan optimum investments over a 20 year planning period for a typical rural water system in Oklahoma. Seasonal household demand for water was estimated. Cost characteristics of rural water systems were analyzed. Nonlinear water demand and supply relationships were included in a separable programming model to determine optimum system capacity, water demand, and financial flows under conditions of marginal cost pricing and maximizing present value of net social benefits over the planning period.

A summary of the thesis and research results are presented in this chapter. Policy implications for rural water system development and management are discussed. Finally, other conclusions and areas for further research are presented.

Summary Results

Rural Water System Characteristics

A rural water system as defined by the FmHA and Oklahoma Rural Water System Association is a system which serves a population of less than 10,000. Oklahoma in 1983 had over 500 rural water systems. A questionnaire was sent to 166 rural water systems to obtain characteristics of the system. Of the 166 systems surveyed, 71 usable surveys were returned for a response rate of 43 percent.

Of the rural water systems which responded 62 percent were incorporated between 1963 and 1972. This compares to 17 percent which were incorporated between 1973 and 1983. Of the respondents 83 percent had expanded since incorporation compared to 14 percent which had not.

The primary sources of water for the rural water systems were groundwater and purchased water. Ground water was the prevelant source of water for the western portion of Oklahoma compared to purchased water for the eastern portion of the state.

The majority of the systems were encouraging the connection of new customers and this was viewed as a way of increasing revenue to the system. However, 21 percent of the systems were not encouraging the connection of new customers. Viewpoints expressed included preservation of the nonmetropolitan atmosphere of the area, lack of adequate capacity in the system, and distance to potential new customers.

Most rural water system managers felt that the water system had kept people from moving and had helped to increase population. The increased rate of home construction and improved fire protection were further attributed to the existence of the rural water system.

Financially, 54 percent of the sample of rural water systems had a positive cash flow in 1983. This compared with 28 percent which had a negative cash flow and 18 percent not responding. Cash flows ranged from a negative $61,231 to a positive $119,723.

Cost functions were estimated for operation and maintenance, water purchase and investment. All cost functions were U-shaped indicated economies of scale exist.

Rural Water System Household Characteristics

Twenty-one rural water systems were surveyed in person with five from each quadrant in the State of Oklahoma and one test system in the northeast quadrant. A 10 percent sample of household users from the 14 systems which provided addresses were mailed a survey questionnaire. Of the 668 surveys mailed, 347 usable surveys were obtained for a 52 percent response rate.

The average size household was 2.8 people with a range from one to 12 people. Of the respondents, 16 percent were 10 years or younger and 19 percent of the population were 60 or over.

Households were asked to indicate an annual income category. The median family income was $22,500 with 23 percent having an annual household income of $10,000 or less and 47 percent having an income of $20,000 or less. Of the households, 17 percent had income of over $40,000.

When asked questions concerning water usage 77 percent of the households felt that they were able to use as much water as they wanted. Most households washed their car using water from the rural water system. However, about half of the households did not use water from the rural water system for gardens, lawns or livestock. Of the respondents 6.6 percent had an alternative source of water for household usage and 31 percent had an alternative source of water for nonhousehold usage. However, only about 2 percent of household water did not come from the rural water system and about 25 percent of nonhousehold water came from an alternative source.

Water demand functions were estimated for the rural households. It was found that seasonal differences exist in the demand for water. The price elasticities for rural water in Oklahoma were -0.28 for winter, -0.80 for spring-fall, and -1.76 for summer. These compare to the price elasticities for urban water as estimated by Charles Howe (1982) of -0.06 for winter and -0.43 for summer. Reasons for differences in the price elasticities between rural and urban users include: (1) rural users frequently have alternative sources of water, and (2) more uses for water exist in rural areas than urban areas.

The demand estimation used marginal price, size of household, income, nonhousehold alternative sources of water, and a difference variable as independent variables. The difference variable is defined as the difference between the actual water bill for a household and the charges for water when priced at the marginal price. The difference variable acts as a surrogate for the real income effect. The expected sign of the difference variable can be either positive or negative depending on whether the rate structure is decreasing or increasing block rate and the relationship to quantity demanded can be nonlinear.

The income elasticity of water demand was estimated at 0.24. The marginal person in a rural household adds 1.17 thousand gallons to monthly water consumption.

A Seasonal Investment Programming Model

A seasonal investment programming model was developed which maximizes present value of net benefits to the system over a 20 year planning period. The model incorporates the estimated monthly household seasonal water demand functions with annual cost functions for operation and maintenance, water purchase, and investment. Mixed integer programming was used to allow for fixed investment costs. The investment cost functions determines the timing and size of investment. The model determines optimal seasonal capacity, water demand, and marginal water price. Separable programming was used to incorporate nonlinear demand and cost relationships. The planning period covered 20 years with five year decision units beginning with the base year of 1983.

Results of the Investment Programming Model

The scenario of a typical rural water system was assumed to have 412 household water taps at initiation and a 4 percent annual growth rate in the number of household taps. The system began operation in the base year with a seasonal capacity of 13,284,840 gallons of water. The present value of net benefits equalled $119,212 for the entire planning period. This indicates a consumers surplus available to households equal to $119,212.

However, valuing all water consumed at the marginal price results in extreme negative cash flows. For the last two decision periods the marginal price of both summer and the spring-fall seasons rises above the marginal cost since price acts as a rationing device to reduce monthly household demand when faced with a fixed capacity. Cash flows become less negative as the marginal price increases relative to the marginal cost and for the summer season of the last decision period it turns positive.

Principles of Water Rate Design

Using the results of the investment programming model for 412 initial household water taps, principles of water rate design were presented. The first is that total revenue must cover total costs on an annual basis. Second, the marginal unit of water consumed should be priced equal to the marginal cost of providing that unit as long as capacity is available. Third, at least two pricing tiers are needed to assure marginal cost pricing of the last unit consumed and sufficient total revenue to cover total cost.

Fourth, fixed costs, including investment and operation and maintenance, should be assessed households on a basis independent of quantity of water consumed. Finally, as the marginal price increases relative to the marginal cost the pricing strategy should take on the form of an increasing block rate so that the price signal conveys to households the capacity restriction is coming into play and water conservation is necessary.

Using the above principles two different water rate structures were analyzed using the results of the programming model. The first water rate structure assumed no connection fee but a high monthly service charge. Net cash flow was close to zero. The second water rate structure assumes a $500 connection fee and a lower monthly service charge. The system shows negative cash flows during early years of the planning period and positive cash flows in later years. These results, however, could easily be modified by changing any of the administered prices.

Policy Implications

Rural water systems in recent years have experienced tremendous growth. Many city and town dwellers searching for an alternative lifestyle have been moving to rural areas. Some rural areas have no source of clean water or an adequate supply of water other than a rural water district. Several issues have come into existence due to this change in living patterns including a need to have clean water. Some of the issues include: are subsidies justified for all rural areas; do monopoly implications of rural water systems warrant public intervention; are management practices giving most efficient use of resources; is investment planning consistent with current growth; and are pricing strategies giving the most efficient use of resources including water. This section deals with the policy implications of these issues.

Subsidies

Current justification for subsidies rests on (1) rural water systems are a decreasing cost industry and result in negative cash flows if marginal cost pricing is used; and (2) many rural areas in Oklahoma are characterized as low income and are in need of safe water supplies. Median family income for households surveyed as members of rural water systems averaged 93 percent of the state median income in 1983. This would suggest that not all rural water systems are justified in receiving subsidies based on family income levels.

Subsidies to a rural water system act as additional revenue to the water system allowing it to cover costs. Subsidies do not change the underlying cost structure or demand conditions expressed in this study. The investment programming results of this study indicate substantial net benefits are potentially available to the typical rural water system in Oklahoma. This means all costs of the system can be met and rural households are still left with considerable consumer's surplus. Rate structures were proposed that capture sufficient consumer's surplus to cover total costs of operation.

Some smaller systems may not be able to operate without the subsidies forcing rural residents to either relocate or seek alternative sources of water. By switching to an alternative source of water the household faces the costs of drilling a well and pumping water to obtain an adequate supply of clean water. Furthermore, aquifers are dynamic and not static. A clean source of water one day does not guarantee a clean source of water the next day. Some small systems may be able to consolidate with other systems and thus take advantage of the substantial economies of scale in operation and maintenance, water purchase and expansion of capacity. Decreasing costs of operation decreases the need for subsidies.

The need for subsidies to supplement revenues of existing or new systems could be decided on an individual basis following a set of guidelines established by a public authority such as the Oklahoma Water Resources Board. The amount of the subsidy could be based on the financial situation of the members and the cost characteristics of the water system.

Monopoly Powers

Rural water systems frequently charge a connection fee for new customers. The fee ranges from some proportion of the actual cost to reserve capacity for delivering water to the customer to a fee greater than the actual investment cost. If a system has an excessive connection fee then it is discriminating against potential customers. If a rural water system is considered like a public utility, and if it discriminates by using a high connection fee, then it is not acting in the best interest of the public at large and public intervention is warranted.

Because of high fixed costs of investment it is doubtful a small number of households could financially afford to start a new system in the area of an existing system and that FmHA would subsidize them. The question remains, are rural water systems that limit connections acting in the best interest of the public or only for the interest of the board of directors and their members.

Management Practices

Members of rural water systems often elect boards of directors to oversee the operation of the system. In some instances board members receive some financial compensation for their service. Few members of the board are familiar with operations of a rural water system and learn from serving. Recordkeeping for some of the systems amount to writing the name of the household on a piece of legal pad paper when they come to pay their bill. Payments are sometimes overlooked or missed. Some systems cannot afford a full-time bookkeeper since their size does not justify it.

The management practices differ greatly. For some systems the manager is the major decision maker and the board follows the manager's advise. While with other systems it is the board of directors who control the decision making process. The problem arises when the decision making unit, either manager or board of directors, is not familiar with the operations of a rural water system. The result can be poor recordkeeping, hiring practices, investment planning or designing of a rate structure.

The Oklahoma Rural Water Association works with rural water systems in the state helping to improve services and recordkeeping practices. Due to their lack of manpower, however, not all systems can be visited. Workshops could be held in various sections of the state through the Oklahoma Rural Water Association or the Cooperative Extension Service dealing with record keeping and management practices to help those board members and managers who lack experience in the operations of rural water systems.

Hiring practices differ greatly between systems. One of the major problems is a high turnover rate among employees. Wages paid employees were characterized as being low by the managers. Various incentives such as free housing or increased time-off were used as additional benefits to supplement low wages. For some systems this is not a problem since the members of the rural water system actually do the maintenance as part-time employment. Many of the management problems are directly related to size of system and this is reflected in the data on costs of operation. Larger systems are able to afford better managers, improve skills of employees and provide more incentives for retaining people, and thus reduce costs of operation.

Investment Planning

From the work of Myoung (1982) it was found that systems normally underbuild capacity. Results of the investment programming model in this study, which is limited to a relatively low discount rate and low growth rate of new customers, show that sufficient capacity should be built in the initial period to serve for the entire planning period. This means having excess capacity for about half of the planning period. The main reason most systems underbuild capacity is associated with the higher annualized cost of fixed investment for the initial users relative to the annualized cost of investment for households which connect to the system later. The initial users are financially constrained as to the size system which can be built. This could justify the use of subsidies to encourage systems to build greater capacities.

Compounding the problem in determining the appropriate size capacity to build is the expected growth in the number of household taps. Projected growth of a system is uncertain. During the oil boom of the late 1970's, some rural water systems expanded substantially to meet the increased water demands of new customers who were working the oil fields. With the end of the oil boom many of these households left resulting in excess capacity for the systems and high annualized investment costs for those households remaining.

As noted earlier some systems use high connection fees to limit problems of growth. Systems which act as public monopolies and do not discriminate do face the problem of projecting growth. Systems close to communities such as Oklahoma City, Tulsa and Stillwater can expect higher rates of growth for surrounding rural areas than do systems that serve mostly rural farming communities.

Pricing Strategies

Several pricing structures were discussed in previous chapters including the increasing and decreasing block rate, fixed rate, connection fees and variations of the above. Little emphasis has been placed on controlling aggregate demand for water to conserve water or to make sure water is priced to reflect relative scarcity of water to society. The one exception, perhaps, is the use of connection fees to expand or limit number of new members. Rural water system managers and advisors to water systems should be trained in the principles of designing water rate structures as discussed in Chapter VI of this study.

Conclusions and Need for Further Research

This section draws together some basic conclucions based on research in this study and from results of other studies pertaining to pricing of water for rural water systems. It also identifies areas for further research which, if carried out, will improve the base of economic information for better management of rural water systems.

1. Rural water systems are shown in this and other studies to have significant economies of scale. Larger size systems are able to deliver water at lower averge costs. This requires careful planning of investments not just for current users but for potential new users. It is costly to expand capacity if growth in demand has been under estimated.

There are economies of scale not only in building capacity but also in operation and maintenance of systems. The consolidation of systems would serve to capture more of the economies of scale associated with operation and maintenance.

Most research on estimating costs of supplying water through rural water systems is based on historical or cross section data. Such studies provide information on costs of existing systems but provide little information useful in planning proposed new systems or consolidation of systems. Research is particularly important on costs of consolidating and expanding systems at regional levels such as is proposed for Eastern Oklahoma. Engineering data on consolidations and expansions is necessary to develop appropriate cost estimates. How water is priced depends heavily on costs of completing these consolidation and expansion activities.

2. Demand for water is price sensitive. Results of water demand estimation in this study using household data indicate a much higher price sensitivity than exists for urban water demand and higher than what has been thought to exist in rural areas previously. Further verification of price elasticities for rural water demand should be done. Seasonality factors in water demand are indicative of high price elasticities for some uses of water.

If the summer quarter price elasticity is truly as elastic as indicated in this study, costs of supplying water in rural areas are extremely important and will have major impacts on investment planning for expanding water system capacities.

3. Projected growth in number of new customers is critical for planning investments in rural water systems. Myoung showed that underestimating growth in aggregate water demand due to growth in number of new customers leads to nonoptimal decisions in timing and size of additions to capacity. Results of surveys done for this study indicate that some systems are compensating for this error by limiting new connections. This brings to the forefront whether rural water systems should be governed as private corporations or public monopolies and whether state regulatory agencies should review management practices. This is of critical concern if public subsidies or government backing of bond issues are to be used.

The costs of over- or under-estimating of growth in aggregate demand should be studied more. Is the problem one of high fixed investment costs or one of a more equitable distribution of costs among users for reserving capacity to latecomers?

4. The need and justification for public subsidies to rural water systems should be reviewed. The results of this study would indicate sufficient benefits to users to insist that they pay close to full social costs of a system. Justification for subsidies based on low incomes of users is less convincing now that survey results indicate comparable family incomes, on the average, of members in systems than exists for the state as a whole. Further analysis of survey results should be done to determine whether full cost pricing will adversely effect the low income and elderly. If subsidies are to be granted to low income rural groups perhaps it should be done on a basis of all groups and not just those connected to a rural water system.

5. Pricing strategies considered in this study were limited to those necessary to insure total revenue equal total cost. Oklahoma is characterized as a state in which water is becoming increasingly scarce. The concept of pricing water according to its replacement cost was introduced in the review chapter but not pursued. Replacement of water coming from nonrechargable aquifers is of increasing concern. Little research has been done on how to incorporate those replacement costs in studies similar to this one.

6. Many rural water systems in Oklahoma, particularly those known as Rural Water Districts, are organized as private corporations. Yet they possess many of the characteristics of a public monopoly. As

decreasing cost industries they are protected to a degree from competition. They are able to set prices. Yet they generally do not seek to maximize profits but, rather, to just maintain a positive cash flow. Many receive subsidies from the federal government and some use government backing to obtain favorable financing rates.

But are rural water systems considered public monopolies? Are they required to accept all new potential members Are they permitted to discriminate among members of a system--charging low volume users at different rates than high volume users. Would a group of potential new members within the regional boundaries of an existing system, if excluded from joining the existing system, be able to obtain grants and subsidies from government as did the existing system? Have rural water systems limited new entries either by not extending connection rights or by charging high connection fees? Is management of rural water systems required to consider competitive bidding on contracts and materials and thus limit payment for goods and services equal to opportunity cost?

This study emphasizes use of economic principles beneficial to society as a whole. Marginal costs are equated with marginal benefits in determining capacity of a system and in supplying water to members of a system. Expected growth in number of members is projected and all members are permitted to connect. All factors contributing to demand and supply of water to rural households are assumed to be known with certainty.

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APPENDIX A

RURAL WATER SYSTEMS MANAGER'S SURVEY

0 1 Card Number _ _ _ _ _ _ _ _

RURAL WATER DISTRICT MANAGERS SURVEY QUESTIONNAIRE Confidential

1. Name of your rural water district? ____________________

Address? ____________________

County? ____________________

2. Name of Manager? ____________________

Telephone No.? ____________________

_ _ (01.07)

3. When was the rural water district incorporated? ____________________

_ _ (01.10)

4. When did users first get water (approximate date)? ____________________

_ _ _ _ _ (01.13)

5. How many users did you have when the water system first went into use? _____

6. Please list the annual number of users since initiation?

	Year		Number
_ _ (05.07)	____	_ _ _ _ _ _ (05.10)	____
_ _ (06.16)	____	_ _ _ _ _ _ (06.19)	____
_ _ (07.25)	____	_ _ _ _ _ _ (07.28)	____
_ _ (08.34)	____	_ _ _ _ _ _ (08.37)	____
_ _ (09.43)	____	_ _ _ _ _ _ (09.46)	____
_ _ (10.52)	____	_ _ _ _ _ _ (10.55)	____
_ _ (11.61)	____	_ _ _ _ _ _ (11.64)	____
_ _ (12.70)	____	_ _ _ _ _ _ (12.73)	____
_ _ (13.07)	____	_ _ _ _ _ _ (13.10)	____
_ _ (14.16)	____	_ _ _ _ _ _ (14.19)	____
_ _ (15.25)	____	_ _ _ _ _ _ (15.28)	____
_ _ (16.34)	____	_ _ _ _ _ _ (16.37)	____
_ _ (17.43)	____	_ _ _ _ _ _ (17.46)	____
_ _ (18.52)	____	_ _ _ _ _ _ (18.55)	____
_ _ (19.61)	____	_ _ _ _ _ _ (19.64)	____

7. How many users of the various categories do you currently have?

_ _ _ _ (01.20) (1) Residential

_ _ _ _ (01.25) (2) Pasture taps

_ _ _ _ (01.30) (3) Business

_ _ _ _ (01.35) (4) Industrial

_ _ _ _ (01.40) (5) Municipal

_ _ (01.45)

8. What is your source of water? (1) Wells (2) Streams (3) Lake (4) Purchased

9. If purchased, from whom? ______________________________

_ (01.47)

10. Do you have a water treatment facility? (1) Yes (2) No

_ (01.49)

11. Has the rural water system been expanded since initiation? (1) Yes (2) No

If yes, were the expansions in water source _____, water treatment _____, and/or water distribution ____?

12. If the expansion was in water distribution, what were the types of expansion?

(1) Additional trunk lines _____ (2) Booster pumps

(3) Storage tanks _____ (4) Parallel lines _____ (5) Buildings _____

(6) Other (specify) ______________________________

When did these expansions occur?

Type of Expansion	Year	Cost
______________	____	________
______________	____	________
______________	____	________
______________	____	________
______________	____	________

13. If the expansion was in water source and water treatment what were the types of expansion?

(1) Wells _____ (2) Reservoir _____ (3) Treatment _____ (4) Other _____

Please specify if other ______________________________

When did the expansions occur?

Type of Expansion	Year	Cost

_ (01.51)

14. Are you encouraging the connection of new customers? (1) Yes (2) No
If no, please explain why not. ____

____

15. Does your water system adequately meet present seasonal demand?
(1) Yes (2) No
If no, please explain. ____

____

16. Who reads the meters? ____

17. What are your major maintenance problems? ____________________________

____

18. What percent of your maintenance work is contracted out? ______________

_ (01.55)

19. Do you have any problems with your water supply? (For example, quantity,
odor, taste) (1) Yes (2) No Comment: ______________________________

____

20. Has the RDW helped to keep people from moving out of your district? ______

____

21. What is the number one complaint of your water users? ________________

____

22. Please indicate which of the following applies to your rural area as a result of the RWD.

				Comment
_ (01.57) a.	increase in the rate of home construction	(1) Yes	(2) No	____________
_ (01.59) b.	increase in population	(1) Yes	(2) No	____________
_ (01.61) c.	improved fire protection	(1) Yes	(2) No	____________
_ (01.63) d.	increase in property value	(1) Yes	(2) No	____________
_ (01.65) e.	increase in livestock enterprises	(1) Yes	(2) No	____________
_ (01.67) f.	new job opportunities in the area served by your RWD	(1) Yes	(2) No	____________
_ (01.69) g.	new business firms in the area served by your RWD	(1) Yes	(2) No	____________
_ (01.71) h.	expansion of existing businesses in the area served by your RWD	(1) Yes	(2) No	____________

23. Please attach or write down your current water rate schedule. ____________

____

____

24. When did this rate become effective? ______________________________

25. When was the water rate last adjusted before the current rate? ____________

26. Please list expenditures excluding investment costs for 1983.

(1) Operation and Maintenance

- (i) Wages ____________
- (ii) Management salaries ____________
- (iii) Office expenses ____________
- (iv) Bond and insurance ____________
- (v) Professional fees ____________
- (vi) Cost of utilities ____________
- (vii) Repair and maintenance ____________
- (viii) Supplies ____________
- (ix) Miscellaneous and other (specify) ____________

  ____

  ____

  ____

Total O &M ____________

(2) Water purchase ____________

(3) Debt service ____________

(4) Other (specify) ____________

____

____

____

Total Expenditure 1983 ____________

27. Please list the investment costs for 1983. ______________________________

____

____

28. Please list the types and amount of revenue for 1983.

(1) Water billings ____________

(2) Initial deposits ____________

(3) Interest received ____________

(4) Connection fees ____________

(5) Reservation fees ____________

(6) Other revenue (specify) ____________

____

____

____

Total Revenue ____________

_ _ _ (01.73)

29. How many miles of line did the system have in 1983? ____________

_ (01.77)

30. Would you like a copy of the results of the survey? (1) Yes (2) No

31. What were your water purchases in gallons for 1983?

____________________ _ _ _ _ _ _ _ _ _ (08.01)

APPENDIX B

RESPONSE TO RURAL WATER SYSTEMS MANAGER'S SURVEY QUESTIONNAIRE

TABLE XXXIV

DOES THE RURAL WATER SYSTEM HAVE THEIR OWN TREATMENT FACILITIES?

Response	No. Obs.	Percent
Yes	23	32
No	46	65
No Response	2	3
	71	100

TABLE XXXV

TYPES OF EXPANSIONS SINCE INITIATION FOR RURAL WATER SYSTEMS, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Type	No. Obs.	Percent
Water Sources	32	45
Water Treatment	14	20
Distribution	55	77

TABLE XXXVI

TYPES OF EXPANSIONS IN WATER DISTRIBUTION FOR RURAL WATER SYSTEMS SINCE INITIATION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Type	No. Obs.	Percent
Trunk Lines	43	72
Booster Pumps	29	48
Storage Tanks	37	62
Parallel Lines	23	38
Buildings	21	35

TABLE XXXVII

TYPES OF EXPANSIONS IN WATER SOURCES OR TREATMENT FACILITIES FOR RURAL WATER SYSTEMS SINCE INITIATION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Type	No. Obs.	Percent
Wells	25	54
Reservoirs	7	15
Treatment Facilities	11	24

TABLE XXXVIII

NUMBER OF RURAL WATER SYSTEMS ENCOURAGING THE CONNECTION OF NEW CUSTOMERS, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Response	No. Obs.	Percent
Yes	51	72
No	15	21
No Response	5	7
	71	100

TABLE XXXIX

NUMBER OF WATER SYSTEMS ADEQUATELY MEETING SEASONAL DEMAND, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Response	No. Obs.	Percent
Yes	47	66
No	21	30
No Response	3	4
	71	100

TABLE XL

PERCENT OF YOUR WATER SYSTEM'S WORK CONTRACTED OUT, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Percent of Contracted Work	No. Obs.	Percent
100	21	30
90-99	5	7
50-89	5	7
1-49	15	21
0	24	34
No Response	1	1
	71	100

TABLE XLI

RURAL WATER SYSTEM HAVING PROBLEMS WITH WATER QUALITY SUCH AS ODOR, COLOR OR TASTE, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Response	No. Obs.	Percent
Yes	20	28
No	51	72
No Response	0	0
	71	100

TABLE XLII

RURAL DEVELOPMENT QUESTIONS, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Question	Yes	(%)	No	(%)	No Response	(%)
Has your RWD helped people from moving?	46	(65)	15	(21)	10	(14)
Has the RWD increased the rate of home construction?	44	(62)	20	(28)	7	(10)
Has the RWD helped to increase population?	45	(63)	17	(24)	9	(13)
Has the RWD helped to improve fire protection?	55	(77)	12	(17)	4	(6)
Has the RWD helped increase livestock operations?	26	(37)	33	(46)	12	(17)
Has the RWD helped create new job opportunities?	17	(24)	43	(61)	11	(15)
Has the RWD helped attract new business firms?	20	(28)	40	(56)	11	(16)
Has the RWD helped with expansion of existing business?	12	(17)	44	(62)	15	(21)

TABLE XLIII

YEAR CURRENT WATER RATE BECAME EFFECTIVE
71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Year	No. Obs.	Percent
1984	13	18
1983	15	21
1982	15	21
1981	13	18
1980	6	9
1979	1	1.5
1978	1	1.5
1974	1	1.5
1973	1	1.5
No Response	5	7
	71	100

TABLE XLIV

LENGTH IN YEARS SINCE WATER RATE WAS LAST ADJUSTED, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Year	No. Obs.	Percent
0	7	10
1	9	13
2	14	20
3	7	10
4	8	11
5	1	1
6	2	3
7	1	1
8	2	3
9	1	1
Over 10	3	4
No Response	16	23

TABLE XLV

NUMBER OF USERS IN 1983, 71 RURAL WATER SYSTEMS, OKLAHOMA

Size	No. Obs.	Percent
Less 100	6	8
101- 200	8	11
201- 300	11	15
301- 400	9	13
401- 500	2	3
501- 600	5	7
601- 700	5	7
701- 800	1	1.5
801- 900	2	3
901-1000	0	0
1001-1100	0	0
1101-1200	4	6
1201-1300	2	3
1301-1400	1	1.5
Over 1401	5	7
No Response	10	14
	71	100

TABLE XLVI

FREQUENCY OF POSITIVE AND NEGATIVE CASH FLOW IN THOUSANDS OF DOLLARS FOR RWD'S, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

Positive and Negative Cash Flow ($1,000)	No. Obs.	Percent
Greater (-$40)	1	1.6
(-$40) - (-$30)	3	5
(-$29) - (-$20)	0	0
(-$19) - (-$10)	5	9
(-$ 9) - 0	11	19
0 - $10	14	24
$11 - $20	7	12
$21 - $30	4	7
$31 - $40	1	1.6
$41 - $50	0	0
$51 - $60	4	7
$61 - $70	1	1.6
$71 - $80	3	5
Over $80	4	7
	58	100

TABLE XLVII

RURAL WATER SYSTEMS ENCOURAGING THE CONNECTION OF NEW CUSTOMERS, BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	20	3	1
Northeast	11	5	1
Southeast	20	5	1
Southwest	8	5	1

TABLE XLVIII

RURAL WATER SYSTEM EXPANSION SINCE INITIATION BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	10	4	0
Northeast	15	1	1
Southeast	23	2	1
Southwest	10	2	2

TABLE XLIX

AVERAGE SIZE WATER SYSTEM BY NUMBER OF TAPS, BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Average Size	Smallest	Largest
Northwest	233	80	365
Northeast	824	11	2,627
Southeast	581	90	1,270
Southwest	560	45	1,400

TABLE L

HAS THE RURAL WATER SYSTEM INCREASED THE RATE OF HOME CONSTRUCTION? BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA

	Yes	No	No Response
Northwest	5	7	2
Northeast	13	2	2
Southeast	18	6	2
Southwest	7	4	3

TABLE LI

HAS THE RURAL WATER SYSTEM HELPED INCREASE THE POPULATION? BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	7	5	2
Northeast	12	2	3
Southeast	18	5	3
Southwest	7	4	3

TABLE LII

HAS THE RURAL WATER SYSTEM IMPROVED FIRE PROTECTION? BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	11	2	1
Northeast	13	2	2
Southeast	22	4	0
Southwest	8	3	3

TABLE LIII

HAS THE RURAL WATER SYSTEM INCREASED THE PROPERTY VALUE? BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	10	2	2
Northeast	15	0	2
Southeast	21	3	2
Southwest	9	2	3

TABLE LIV

HAS THE RURAL WATER SYSTEM RESULTED IN INCREASED LIVESTOCK ENTERPRISES? BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	4	6	4
Northeast	5	10	2
Southeast	7	14	5
Southwest	7	4	3

TABLE LV

HAS THE RURAL WATER SYSTEM CREATED NEW JOB OPPORTUNITIES? BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	2	9	3
Northeast	4	11	2
Southeast	7	15	4
Southwest	3	7	4

TABLE LVI

HAS THE RURAL WATER SYSTEM ATTRACTED NEW BUSINESS FIRMS TO THE AREA? BY REGION, 71 RURAL WATER SERVICES, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	1	10	3
Northeast	5	9	3
Southeast	11	13	2
Southwest	3	6	5

TABLE LVII

HAS THE RURAL WATER SYSTEM RESULTED IN THE EXPANSION OF EXISTING BUSINESSES? BY REGION, 71 RURAL WATER SYSTEMS, OKLAHOMA, 1983

	Yes	No	No Response
Northwest	1	10	3
Northeast	4	10	3
Southeast	5	15	6
Southwest	2	7	5

APPENDIX C

RURAL WATER SYSTEM PRICING STRATEGIES

1.	Service charge for 0 gallons	$17.00
	Remainder	$3.00 per thousand gallons
2.	Service charge for 2,000 gallons	$8.50
	Next 3,000 gallons	$1.25 per thousand gallons
	Next 2,000 gallons	$0.85 per thousand gallons
	Remainder	$0.75 per thousand gallons
3.	Service charge for 2,000 gallons	$11.00
	Next 2,000 gallons	$2.00 per thousand gallons
	Remainder	$2.50 per thousand gallons
4.	Service charge for 2,000 gallons	$11.00
	Remainder	$2.25 per thousand gallons
5.	Service charge for 1,000 gallons	$6.00
	Next 1,000 gallons	$3.60 per thousand gallons
	Next 2,000 gallons	$2.40 per thousand gallons
	Next 6,000 gallons	$2.16 per thousand gallons
	Next 10,000 gallons	$2.04 per thousand gallons
	Next 10,000 gallons	$1.98 per thousand gallons
	Remainder	$0.84 per thousand gallons
6.	Service charge for 3,000 gallons	$6.90
	Remainder	$1.00 per thousand gallons
7.	Service charge for 0 gallons	$12.50
	Remainder	$2.25 per thousand gallons
8.	Service charge for 1,000 gallons	$6.00
	Next 2,000 gallons	$1.25 per thousand gallons
	Next 2,000 gallons	$1.00 per thousand gallons
	Remainder	$0.75 per thousand gallons
9.	Service charge for 3,000 gallons	$7.00
	Next 1,000 gallons	$1.75 per thousand gallons
	Next 1,000 gallons	$1.50 per thousand gallons
	Next 1,000 gallons	$1.40 per thousand gallons
	Next 1,000 gallons	$1.30 per thousand gallons
	Next 1,000 gallons	$1.20 per thousand gallons
	Next 1,000 gallons	$1.10 per thousand gallons
	Next 1,000 gallons	$1.00 per thousand gallons
	Next 1,000 gallons	$0.90 per thousand gallons
	Next 1,000 gallons	$0.80 per thousand gallons
	Next 1,000 gallons	$0.70 per thousand gallons
	Remainder	$0.50 per thousand gallons

10.	Service charge for 1,000 gallons	$9.50
	Next 3,000 gallons	$2.20 per thousand gallons
	Next 2,000 gallons	$2.10 per thousand gallons
	Next 2,000 gallons	$2.00 per thousand gallons
	Next 2,000 gallons	$1.90 per thousand gallons
	Next 2,000 gallons	$1.80 per thousand gallons
	Next 2,000 gallons	$1.70 per thousand gallons
	Next 2,000 gallons	$1.60 per thousand gallons
	Next 2,000 gallons	$1.50 per thousand gallons
	Next 2,000 gallons	$1.40 per thousand gallons
	Next 2,000 gallons	$1.30 per thousand gallons
	Next 2,000 gallons	$1.20 per thousand gallons
	Next 2,000 gallons	$1.10 per thousand gallons
	Remainder	$1.00 per thousand gallons
11.	Service charge for 1,000 gallons	$2.00 per thousand gallons
	Next 9,000 gallons	$1.75 per thousand gallons
	Next 90,000 gallons	$1.50 per thousand gallons
	Remainder	$1.25 per thousand gallons
12.	Service charge for 2,000 gallons	$9.50
	Next 3,000 gallons	$3.00 per thousand gallons
	Next 5,000 gallons	$2.00 per thousand gallons
	Next 10,000 gallons	$1.00 per thousand gallons
	Remainder	$0.75 per thousand gallons
13.	Service charge for 1,000 gallons	$3.25
	Next 1,000 gallons	$3.25 per thousand gallons
	Next 1,000 gallons	$2.75 per thousand gallons
	Next 1,000 gallons	$2.00 per thousand gallons
	Next 1,000 gallons	$1.25 per thousand gallons
	Remainder	$1.10 per thousand gallons
14.	Service charge for 1,000 gallons	$9.00
	Next 1,000 gallons	$4.00 per thousand gallons
	Next 1,000 gallons	$3.50 per thousand gallons
	Next 1,000 gallons	$2.50 per thousand gallons
	Next 1,000 gallons	$2.00 per thousand gallons
	Remainder	$1.00 per thousand gallons
15.	Service charge for 1,500 gallons	$5.00
	Remainder	$1.00 per thousand gallons
16.	Service charge for 1,000 gallons	$9.75
	Next 3,000 gallons	$3.00 per thousand gallons
	Remainder	$2.50 per thousand gallons
17.	Service charge for 3,000 gallons	$6.00
	Next 8,000 gallons	$1.00 per thousand gallons
	Next 9,000 gallons	$0.65 per thousand gallons
	Remainder	$0.55 per thousand gallons

18.	Service charge for 1,000 gallons	$14.50
	Next 3,000 gallons	$3.50 per thousand gallons
	Remainder	$1.50 per thousand gallons
19.	Service charge for 2,000 gallons	$6.50
	Remainder	$0.90 per thousand gallons
20.	Service charge for 2,000 gallons	$10.00
	Next 18,000 gallons	$2.50 per thousand gallons
	Remainder	$1.50 per thousand gallons
21.	Service charge for 4,000 gallons	$10.00
	Next 6,000 gallons	$0.75 per thousand gallons
	Remainder	$0.50 per thousand gallons
22.	Service charge for 1,000 gallons	$14.50
	Remainder	$1.50 per thousand gallons
23.	Service charge for 2,000 gallons	$7.50
	Next 1,000 gallons	$2.50 per thousand gallons
	Remainder	$1.90 per thousand gallons
24.	Service charge for 2,000 gallons	$8.50
	Remainder	$2.00 per thousand gallons
25.	Service charge for 2,000 gallons	$17.25
	Remainder	$1.25 per thousand gallons
26.	Service charge for 1,000 gallons	$12.00
	Next 1,000 gallons	$2.50 per thousand gallons
	Next 2,000 gallons	$2.00 per thousand gallons
	Next 3,000 gallons	$1.75 per thousand gallons
	Remainder	$1.50 per thousand gallons
27.	Service charge for 1,000 gallons	$5.90
	Remainder	$1.15 per thousand gallons
28.	Service charge for 2,000 gallons	$9.00
	Next 6,000 gallons	$2.00 per thousand gallons
	Remainder	$1.50 per thousand gallons
29.	Service charge for 1,000 gallons	$10.00
	Next 4,000 gallons	$1.80 per thousand gallons
	Remainder	$1.40 per thousand gallons
30.	Service charge for 1,000 gallons	$13.00
	Remainder	$1.70 per thousand gallons
31.	Service charge for 1,000 gallons	$10.00
	Remainder	$2.00 per thousand gallons
32.	Service charge for 1,000 gallons	$10.00
	Remainder	$0.50 per thousand gallons

33.	Service charge for 1,000 gallons	$12.50
	Next 4,000 gallons	$2.50 per thousand gallons
	Next 1,000 gallons	$1.75 per thousand gallons
	Remainder	$1.50 per thousand gallons
34.	Service charge for 2,000 gallons	$6.00
	Remainder	$1.20 per thousand gallons
35.	Service charge for 2,000 gallons	$13.50
	Next 2,000 gallons	$4.50 per thousand gallons
	Next 1,000 gallons	$2.25 per thousand gallons
	Remainder	$1.00 per thousand gallons
36.	Service charge for 1,000 gallons	$9.90
	Next 4,000 gallons	$4.40 per thousand gallons
	Next 5,000 gallons	$3.50 per thousand gallons
	Remainder	$3.00 per thousand gallons
37.	Service charge for 2,000 gallons	$4.50
	Next 2,000 gallons	$0.95 per thousand gallons
	Next 31,000 gallons	$0.70 per thousand gallons
	Remainder	$0.60 per thousand gallons
38.	Service charge for 2,000 gallons	$15.50
	Remainder	$1.25 per thousand gallons
39.	Service charge for 1,000 gallons	$5.50
	Next 4,000 gallons	$1.50 per thousand gallons
	Remainder	$1.35 per thousand gallons
40.	Service charge for 1,000 gallons	$11.00
	Next 4,000 gallons	$4.50 per thousand gallons
	Next 6,000 gallons	$3.00 per thousand gallons
	Remainder	$1.00 per thousand gallons
41.	Service charge for 2,000 gallons	$9.50
	Next 4,000 gallons	$1.50 per thousand gallons
	Remainder	$0.85 per thousand gallons
42.	Service charge for 1,000 gallons	$7.00
	Next 9,000 gallons	$1.90 per thousand gallons
	Next 10,000 gallons	$1.60 per thousand gallons
	Remainder	$1.50 per thousand gallons
43.	Service charge for 1,000 gallons	$9.00
	Next 1,000 gallons	$2.75 per thousand gallons
	Next 2,000 gallons	$2.50 per thousand gallons
	Remainder	$2.00 per thousand gallons
44.	Service charge for 2,000 gallons	$87.00
	Next 1,000 gallons	$1.00 per thousand gallons
	Remainder	$0.80 per thousand gallons

45.	Service charge for 1,000 gallons	$5.00
	Remainder	$3.00 per thousand gallons
46.	Service charge for 1,000 gallons	$8.00
	Remainder	$3.00 per thousand gallons
47.	Service charge for 2,000 gallons	$10.00
	Next 2,000 gallons	$2.00 per thousand gallons
	Remainder	$2.50 per thousand gallons
48.	Service charge for 2,000 gallons	$16.50
	Next 3,000 gallons	$2.15 per thousand gallons
	Remainder	$1.15 per thousand gallons
49.	Service charge for 3,000 gallons	$8.00
	Remainder	$2.00 per thousand gallons
50.	Service charge for 2,000 gallons	$4.00
	Next 3,000 gallons	$0.80 per thousand gallons
	Next 5,000 gallons	$0.70 per thousand gallons
	Next 5,000 gallons	$0.60 per thousand gallons
	Next 10,000 gallons	$0.50 per thousand gallons
	Next 10,000 gallons	$0.40 per thousand gallons
	Next 10,000 gallons	$0.30 per thousand gallons
	Remainder	$0.20 per thousand gallons
51.	Service charge for 2,000 gallons	$5.00
	Remainder	$0.60 per thousand gallons
52.	Service charge for 3,000 gallons	$7.00
	Remainder	$1.50 per thousand gallons
53.	Service charge for 1,000 gallons	$9.50
	Next 1,000 gallons	$3.00 per thousand gallons
	Next 2,000 gallons	$2.25 per thousand gallons
	Next 1,000 gallons	$2.00 per thousand gallons
	Remainder	$1.20 per thousand gallons
54.	Service charge for 1,000 gallons	$18.00
	Next 2,000 gallons	$3.00 per thousand gallons
	Next 4,000 gallons	$2.80 per thousand gallons
	Remainder	$2.50 per thousand gallons
55.	Service charge for 2,000 gallons	$6.00
	Next 1,000 gallons	$2.50 per thousand gallons
	Next 2,000 gallons	$1.75 per thousand gallons
	Remainder	$2.50 per thousand gallons

56.	Service charge for 1,000 gallons	$8.50
	Next 1,000 gallons	$2.50 per thousand gallons
	Next 1,000 gallons	$2.00 per thousand gallons
	Next 1,000 gallons	$1.00 per thousand gallons
	Next 6,000 gallons	$0.80 per thousand gallons
	Remainder	$0.60 per thousand gallons
57.	Service charge for 2,000 gallons	$6.00
	Next 8,000 gallons	$1.00 per thousand gallons
	Next 10,000 gallons	$0.90 per thousand gallons
	Remainder	$0.75 per thousand gallons
58.	Service charge for 1,000 gallons	$8.00
	Remainder	$1.75 per thousand gallons

APPENDIX D

RURAL WATER SYSTEM HOUSEHOLD SURVEY

0 5 Card Number

RURAL WATER DISTRICT HOUSEHOLD SURVEY Confidential

1. Name and number of your Rural Water District? __________

2. Your mailing address? ____

_ _ (05.11)

3. Number of individuals in household by age group?

_ (05.16) (1) 0- 5 __ _ (05.18) (2) 6-10 __ _ (05.20) (3) 11-14 __

_ (05.22) (4) 15-19 __ _ (05.24) (5) 20-29 __ _ (05.26) (6) 30-39 __

_ (05.28) (7) 40-49 __ _ (05.30) (8) 50-59 __ _ (05.32) (9) 60 + __

_ _ (05.34)

4. Occupation (Head of Household). Please circle.

(1) Professional
(2) Manager; administrator
(3) Sales; clerical
(4) Craftsman
(5) Laborer; operator
(6) Service worker
(7) Farmer or farm worker
(8) Housewife
(9) Student
(10) Retired
(11) Not employed
(12) Other ______________

5. Typical or normal workweek of head of household? (hours) _ _ (05.37)

6. Place of employment of head of household? ______________________________

7. How far do you drive to work (one way)? _________________ (05.40) _ _

_ (05.44)

8. Type of residence?

(1) Mobile home (2) House (3) Duplex (4) Apartment

_ (05.46)

9. Were you one of the original water district members? (1) Yes (2) No

10. What year did you first get water from the system? _ _ _ _ (05.48)

11. How long have you resided at your current residence? _ _ (05.53)

Rural Water District Household Survey (continued)

_ (05.56)

12. Did you move to your current residence from a:

    (1) Location in the same rural water district
    (2) Location in the same county
    (3) Location in Oklahoma
    (4) Location outside Oklahoma

_ (05.59)

13. Type of area moved from:

    (1) Farm (2) Rural nonfarm (3) Town (4) Urban

_ (05.62)

14. What was your reason for moving to the rural water district?

(1) To obtain employment	(2) Transfer by employer
(3) Preference for rural living	(4) To change lifestyle
(5) Dislike other residence	(6) Other ____________________

_ (05.64)

15. How would you compare the quality of this water with the water you were using before?

    (1) Better (2) As good as (3) Worse than

_ (05.66)

16. Are you able to use as much water as you need any time that you like?

    (1) Yes (2) No Comment: ______________________________

    ____

17. Do you use water from the system:

_ (05.68)	(a) to wash your car?	(1) Yes	(2) No
_ (05.70)	(b) to water your garden?	(1) Yes	(2) No
_ (05.72)	(c) for lawn sprinkling?	(1) Yes	(2) No

_ _ _ _ _ (05.74) MN

Rural Water District Household Survey (continued)

0 6 Card Number

_ (06.05)

18. Do you water livestock from the system? (1) Yes (2) No

19. What percent of your water would you estimate is:

(1) household _____ ___ (06.07)
(2) nonhousehold _____ ___ (06.11)
Total 100%

20. Do you have an alternative source of water such as wells or ponds for:

(1) household usage __ Yes __ No _ (06.15)
(2) nonhousehold usage __ Yes __ No _ (06.17)

21. What percent of your household water is from:

(1) your rural water district? _____ ___ (06.19)
(2) alternative sources? _____ ___ (06.23)
Total 100%

22. What percent of your nonhousehold water is from:

(1) your rural water district? _____ ___ (06.27)
(2) alternative sources? _____ ___ (06.31)
Total 100%

___ (06.35)

23. Please circle which category your total 1983 household income belongs? (Include all sources of income. Examples, wages, salaries, pensions, social security, welfare, dividends, etc.)

(1)	Less than $ 5,000	(2)	$ 5,001 to $ 10,000
(3)	$10,001 to $15,000	(4)	$15,001 to $ 20,000
(5)	$20,001 to $25,000	(6)	$25,001 to $ 30,000
(7)	$30,001 to $35,000	(8)	$35,001 to $ 40,000
(9)	$40,001 to $45,000	(10)	$45,001 to $ 50,000
(11)	$50,001 to $55,000	(12)	$55,001 to $ 60,000
(13)	$60,001 to $70,000	(14)	$70,001 to $ 80,000
(15)	$80,001 to $90,000	(16)	$90,001 to $100,000
(17)	Over $100,000		

24. Please make any general comments you desire on the development and operation of the rural water district?

____

____

Rural Water District Household Survey (continued)

_ (06.40)

25. Would you like a copy of the results of the survey? (1) Yes (2) No

_ (06.42) Region _ _ (06.44) District _ _ _ (06.47) Number

_ (06.52) Household _ _ _ _ _ (06.55) MN

Please return to:

Lynn Dellenbarger
Department of Agricultural Economics
Oklahoma State University
Stillwater, OK 74078

APPENDIX E

TESTS FOR STRUCTURAL STABILITY

A test for structural stability was used to determine the difference in intercepts and slopes for the estimated monthly household seasonal demand functions. By using an F-test linear restrictions could be determined. The following test was used:

$$\frac{[\text{ESS (constrained)} - \text{ESS (unconstrained)}]/R}{\text{ESS (unconstrained)}/(T-K)}$$

where R is the number of restrictions, T is the number of observations, and K is the number of regressors in the unconstrained regression.

The demand function was tested for quarterly (seasonal) differences in intercept and slopes of the marginal price and difference variable. The first quarter (January-March) was the standard for which all other quarters were tested against. The variables are defined as:

MW = average monthly water usage by quarter per household in thousands of gallons

MP = marginal price in dollars per thousand gallons

D = difference variable and is equal to the actual water bill less the water bill if water was priced at the marginal price

INCOM = 1983 annual household income in thousands of dollars

SIZH = number of people in household

NHALT = percent of nonhousehold water from alternative sources

D_1 = dummy variable for the second (April-June) quarter

D_2 = dummy variable for the third (July-September) quarter

D_3 = dummy variable for the fourth (October-December) quarter

Tests for structural stability resulted in the following equations. The error sums of squares (ESS) and F values are included.

$$\begin{array}{llllll} MW & = 12.80 - 9.47MP & + 1.88MP^2 & - 0.69D & + 0.08D^2 & \\ t & \quad (3.52)(-2.96) & (2.22) & (-1.12) & (2.29) & \\ & + 0.06INCOM & + 1.17SIZH & - 0.01NHALT & & \\ & \quad (2.78) & (3.60) & (-0.60) & & \end{array} \qquad (A.1)$$

ESS = 12474.56 F statistic = 16.59

$$\begin{array}{llllll} MW & = 12.89 - 0.37D_1 & - 9.53MP & + 1.90MP^2 & - 0.69D & \\ t & \quad (3.53)(-0.41) & (-2.97) & (2.24) & (-1.11) & \\ & + 0.08D^2 & + 0.06INCOM & + 1.17SIZH & - 0.01NHALT & \\ & \quad (2.27) & (2.80) & (3.59) & (-0.60) & \end{array} \qquad (A.2)$$

ESS = 12467.29 F statistic = 0.17

$$\begin{array}{llllll} MW & = 10.82 + 3.09D_2 & - 8.09MP & + 1.58MP^2 & - 0.79D & \\ t & \quad (3.00)\ (3.69) & (-2.56) & (1.90) & (-1.32) & \\ & + 0.08D^2 & + 0.07INCOM & + 1.21SIZH & - 0.01NHALT & \\ & \quad (2.47) & (3.10) & (3.78) & (-0.73) & \end{array} \qquad (A.3)$$

ESS = 11910.11 F statistic = 13.60

$$\begin{array}{llllll} MW & = 12.73 - 1.78D_3 & - 8.68MP & + 1.66MP^2 & - 0.75D & \\ t & \quad (3.52)(-1.95) & (-2.69) & (1.95) & (-1.22) & \\ & + 0.09D^2 & + 0.06INCOM & + 1.16SIZH & - 0.01NHALT & \\ & \quad (2.47) & (2.67) & (3.57) & (-0.62) & \end{array} \qquad (A.4)$$

ESS = 12311.68 F statistic = 3.80

$$\begin{array}{llllll} MW & = 12.87 - 9.53MP & - 0.18MPD_1 & + 1.92MP^2 & - 0.70D & \\ t & \quad (3.53)(-2.97) & (-0.39) & (2.25) & (-1.13) & \\ & + 0.08D^2 & + 0.06INCOM & + 1.17SIZH & - 0.01NHALT & \\ & \quad (2.29) & (2.80) & (3.59) & (-0.60) & \end{array} \qquad (A.5)$$

ESS = 12467.92 F statistic = 0.15

$$\begin{array}{llllll} \mathrm{MW} & = 12.65 & - 9.40\mathrm{MP} & - 1.19\mathrm{MPD}_2 & + 1.80\mathrm{MP}^2 & - 0.76\mathrm{D} \\ t & (3.51) & (-2.96) & (2.61) & (2.64) & (-1.24) \end{array}$$

$$\begin{array}{llll} + 0.08\mathrm{D}^2 & + 0.07\mathrm{INCOM} & + 1.20\mathrm{SIZH} & - 0.01\mathrm{NHALT} \\ (2.38) & (2.93) & (3.71) & (-0.68) \end{array} \qquad (\mathrm{A}.6)$$

ESS = 12184.26 F statistic = 6.83

$$\begin{array}{llllll} \mathrm{MW} & = 12.40 & - 8.87\mathrm{MP} & - 0.60\mathrm{MPD}_3 & + 1.75\mathrm{MP}^2 & - 0.68\mathrm{D} \\ t & (3.40) & (-2.74) & (-2.14) & (2.05) & (-1.10) \end{array}$$

$$\begin{array}{llll} + 0.08\mathrm{D}^2 & + 0.06\mathrm{INCOM} & + 1.16\mathrm{SIZH} & - 0.01\mathrm{NHALT} \\ (2.30) & (2.69) & (3.57) & (-0.61) \end{array} \qquad (\mathrm{A}.7)$$

ESS = 12204.61 F statistic = 6.39

$$\begin{array}{llllll} \mathrm{MW} & = 12.94 & - 9.65\mathrm{MP} & - 1.96\mathrm{MPD}_2 & - 0.09\mathrm{MP}^2\mathrm{D1} & - 0.70\mathrm{D} \\ t & (3.54) & (-2.98) & (2.26) & (-0.45) & (-1.13) \end{array}$$

$$\begin{array}{llll} + 0.08\mathrm{D}^2 & + 0.06\mathrm{INCOM} & + 1.17\mathrm{SIZH} & - 0.01\mathrm{NHALT} \\ (2.30) & (2.80) & (3.60) & (-0.60) \end{array} \qquad (\mathrm{A}.8)$$

ESS = 12465.68 F statistic = 0.20

$$\begin{array}{llllll} \mathrm{MW} & = 13.01 & - 9.50\mathrm{MP} & + 1.79\mathrm{MP}_2 & + 0.37\mathrm{MP}^2\mathrm{D}_2 & - 0.74\mathrm{D} \\ t & (3.59) & (-2.98) & (2.13) & (1.85) & (-1.20) \end{array}$$

$$\begin{array}{llll} + 0.08\mathrm{D}^2 & + 0.07\mathrm{INCOM} & + 1.19\mathrm{SIZH} & - 0.01\mathrm{NHALT} \\ (2.33) & (2.85) & (3.67) & (-0.65) \end{array} \qquad (\mathrm{A}.9)$$

ESS = 12328.04 F statistic = 3.41

$$\begin{array}{llllll} \mathrm{MW} & = 12.55 & - 9.20\mathrm{MP} & - 1.82\mathrm{MPD}_2 & - 0.14\mathrm{MP}^2\mathrm{D}_3 & - 0.67\mathrm{D} \\ t & (3.43) & (-2.84) & (2.15) & (-2.45) & (-1.09) \end{array}$$

$$\begin{array}{llll} + 0.08\mathrm{D}^2 & + 0.06\mathrm{INCOM} & + 1.17\mathrm{SIZH} & - 0.01\mathrm{NHALT} \\ (2.27) & (2.73) & (3.58) & (-0.60) \end{array} \qquad (\mathrm{A}.10)$$

ESS = 12274.02 F statistic = 4.69

$$\begin{array}{ll} MW & = 12.80 - 9.63MP - 1.93MP_2 - 0.66D - 0.06DD_1 \\ t & \quad (3.51)(-2.99) \quad (2.27) \quad (-1.05)\ (-0.55) \end{array}$$

$$\begin{array}{l} + 0.08D^2 + 0.07INCOM + 1.17SIZH - 0.01NHALT \\ \quad (2.22) \quad (2.82) \qquad (3.59) \quad (-0.59) \end{array} \qquad (A.11)$$

ESS = 12461.54 F statistic = 0.30

$$\begin{array}{ll} MW & = 11.45 - 7.75MP + 1.47MP_2 - 0.88D - 0.38DD_2 \\ t & \quad (3.20)(-2.44) \quad (1.76) \quad (-1.46)\ (-3.70) \end{array}$$

$$\begin{array}{l} + 0.08D^2 + 0.07INCOM + 1.20SIZH - 0.01NHALT \\ \quad (2.42) \quad (3.13) \qquad (3.76) \quad (-0.79) \end{array} \qquad (A.12)$$

ESS = 11905.72 F statistic = 13.72

$$\begin{array}{ll} MW & = 12.24 - 8.06MP + 1.50MP_2 - 0.82D - 0.23DD_3 \\ t & \quad (3.37)(-2.47) \quad (1.75) \quad (-1.33)\ (-1.03) \end{array}$$

$$\begin{array}{l} + 0.09D^2 + 0.06INCOM + 1.16SIZH - 0.01NHALT \\ \quad (2.68) \quad (2.66) \qquad (3.56) \quad (-0.69) \end{array} \qquad (A.13)$$

ESS = 12390.28 F statistic = 1.95

$$\begin{array}{ll} MW & = 12.74 - 9.69MP + 1.95MP_2 - 0.64D - 0.07D^2 \\ t & \quad (3.50)(-3.00) \quad (2.28) \quad (-1.02)\ (-2.21) \end{array}$$

$$\begin{array}{l} + 0.01D^2D_1 + 0.07INCOM + 1.17SIZH - 0.01NHALT \\ (-0.58) \qquad (2.83) \qquad (3.59) \quad (-0.60) \end{array} \qquad (A.14)$$

ESS = 12459.75 F statistic = 0.34

$$\begin{array}{ll} MW & = 11.56 - 7.93MP - 1.50MP_2 - 0.74D - 0.07D^2 \\ t & \quad (3.20)(-2.48) \quad (1.78) \quad (-1.21) \quad (2.06) \end{array}$$

$$\begin{array}{l} + 0.03D^2D_2 + 0.07INCOM + 1.19SIZH - 0.01NHALT \\ \quad (3.03) \qquad (3.07) \qquad (3.71) \quad (-0.82) \end{array} \qquad (A.15)$$

ESS = 12087.35 F statistic = 9.19

$$\begin{array}{ll} MW & = 12.51 - 8.03MP + 1.50MP_2 - 0.96D - 0.10D^2 \\ t & \quad (3.45)(-2.44) \quad (1.72) \quad (-1.51) \quad (2.79) \end{array}$$

$$\begin{array}{l} + 0.02D^2D_3 + 0.06INCOM + 1.16SIZH - 0.01NHALT \\ (-1.75) \qquad (2.69) \qquad (3.56) \quad (-0.72) \end{array} \qquad (A.16)$$

ESS = 12342.73 F statistic = 3.07

APPENDIX F

KUHN-TUCKER CONDITIONS

The Kuhn-Tucker conditions are met with the following results:

$$\frac{\partial L}{\partial W1} = \sum_{\tau s} d_{\tau} \overline{B}_{\tau s} - a \sum_{s} \overline{Q1}_{\tau s} \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial W1} \; W2 = 0 \tag{B.1}$$

$$\frac{\partial L}{\partial W2} = d_{\tau} \overline{C}_{\tau s} - b \sum_{s} \overline{Q2}_{\tau s} \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial W2} \; W2 = 0 \tag{B.2}$$

$$\frac{\partial L}{\partial W3} = d_{\tau} \overline{D}_{\tau s} - c \sum_{s} \overline{Q3}_{\tau s} \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial W3} \; W3 = 0 \tag{B.3}$$

$$\frac{\partial L}{\partial W4} = d_{\tau} \overline{E}_{\tau s} - d \sum_{s} \overline{Q4}_{\tau s} \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial W4} \; W4 = 0 \tag{B.4}$$

$$\frac{\partial L}{\partial W5} = d_{\tau} \overline{J}_{\tau s} - 1 \sum_{s} \overline{Q5}_{\tau s} \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial W5} \; W5 = 0 \tag{B.5}$$

$$\frac{\partial L}{\partial W6} = d_{\tau} \overline{P}_{\tau s} - n \sum_{s} \overline{Q6}_{\tau s} \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial W6} \; W6 = 0 \tag{B.6}$$

$$\frac{\partial L}{\partial Q1} = a-k-p \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial Q1} \; Q1 = 0 \tag{B.7}$$

$$\frac{\partial L}{\partial Q2} = b-k-q \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial Q2} \; Q2 = 0 \tag{B.8}$$

$$\frac{\partial L}{\partial Q3} = c-k-t \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial Q3} \; Q3 = 0 \tag{B.9}$$

$$\frac{\partial L}{\partial Q4} = d-k-u \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial Q4} \; Q4 = 0 \tag{B.10}$$

$$\frac{\partial L}{\partial Q} = k-1-n \geq 0 \qquad \text{and} \quad \frac{\partial L}{\partial Q} \; Q = 0 \tag{B.11}$$

$$\frac{\partial L}{\partial S} = -\beta K \sum_{\tau=0}^{T} \sum_{y=(\tau)\overline{y}}^{Y} \alpha_{y} + p+q+t+v+u \leq 0 \qquad \text{and} \quad \frac{\partial L}{\partial S} \; S = 0 \tag{B.12}$$

$$\frac{\partial L}{\partial Z} = -\beta f \sum_{\tau=0}^{T} \sum_{y=(\tau)\overline{y}}^{Y} \alpha_{y} + v\overline{S} \leq 0 \qquad \text{and} \quad \frac{\partial L}{\partial S} \; Z = 0 \tag{B.13}$$

$$\frac{\partial L}{\partial a} = -(\sum_{s} \overline{Q1}_{\tau s} W1_{\tau s} - Q1_{\tau}) \geq 0 \qquad \text{if} >, \quad \pi = 0 \tag{B.14}$$

$$\frac{\partial L}{\partial b} = -(\sum_{s} \overline{Q2}_{\tau s} W2_{\tau s} - Q2_{\tau}) \geq 0 \qquad \text{if} >, \quad L = 0 \tag{B.15}$$

$$\frac{\partial L}{\partial c} = -(\sum_{s} \overline{Q3}_{\tau s} W3_{\tau s} - Q3_{\tau}) \geq 0 \qquad \text{if} >, \quad \sigma = 0 \tag{B.16}$$

$$\frac{\partial L}{\partial d} = -(\sum_{s} \overline{Q4}_{\tau s} W4_{\tau s} - Q4_{\tau}) \geq 0 \qquad \text{if} >, \quad \mu = 0 \tag{B.17}$$

$$\frac{\partial L}{\partial e} = -(\sum_{s} W1_{\tau s} - h_{\tau}) \geq 0 \qquad \text{if } >, \qquad e = 0 \tag{B.18}$$

$$\frac{\partial L}{\partial g} = -(\sum_{s} W2_{\tau s} - h_{\tau}) \geq 0 \qquad \text{if } >, \qquad g = 0 \tag{B.19}$$

$$\frac{\partial L}{\partial i} = -(\sum_{s} W3_{\tau s} - h_{\tau}) \geq 0 \qquad \text{if } >, \qquad i = 0 \tag{B.20}$$

$$\frac{\partial L}{\partial j} = -(\sum_{s} W4_{\tau s} - h_{\tau}) \geq 0 \qquad \text{if } >, \qquad j = 0 \tag{B.21}$$

$$\frac{\partial L}{\partial k} = -(Q1_{\tau} + Q2_{\tau} + Q3_{\tau} + Q4_{\tau} - Q_{\tau}) = 0 \qquad \text{if } \gtrless, \qquad k = 0 \tag{B.22}$$

$$\frac{\partial L}{\partial l} = -(Q_{\tau} - \sum_{s} \bar{Q}5_{\tau s}\ W5_{\tau s}) = 0 \qquad \text{if } \gtrless, \qquad l = 0 \tag{B.23}$$

$$\frac{\partial L}{\partial m} = -(\sum_{s} W5_{\tau s} - 1) \geq 0 \qquad \text{if } >, \qquad m = 0 \tag{B.24}$$

$$\frac{\partial L}{\partial n} = -(Q_{\tau} - \sum_{s} \bar{Q}6_{\tau s}\ W6_{\tau s}) = 0 \qquad \text{if } \gtrless, \qquad n = 0 \tag{B.25}$$

$$\frac{\partial L}{\partial o} = -(\sum_{s} W6_{\tau}{}^{s} - 1) \geq 0 \qquad \text{if } >, \qquad o = 0 \tag{B.26}$$

$$\frac{\partial L}{\partial p} = -(Q1_{\tau} - \sum_{\tau=1}^{G} S_{\tau}) \geq 0 \qquad \text{if } >, \qquad p = 0 \tag{B.27}$$

$$\frac{\partial L}{\partial q} = -(Q2_{\tau} - \sum_{\tau=1}^{G} S_{\tau}) \geq 0 \qquad \text{if } >, \qquad q = 0 \tag{B.28}$$

$$\frac{\partial L}{\partial t} = -(Q3_{\tau} - \sum_{\tau=1}^{G} S_{\tau}) \geq 0 \qquad \text{if } >, \qquad t = 0 \tag{B.29}$$

$$\frac{\partial L}{\partial u} = -(Q4_{\tau} - \sum_{\tau=1}^{G} S_{\tau}) \geq 0 \qquad \text{if } >, \qquad u = 0 \tag{B.30}$$

$$\frac{\partial L}{\partial v} = -(S_{\tau} - \bar{S}Z_{\tau}) \geq 0 \qquad \text{if } >, \qquad v = 0 \tag{B.31}$$

VITA 2

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