AN EMPIRICAL INVESTIGATION INTO THE ECONOMIES OF SIZE FOR OKLAHOMA RURAL WATER SYSTEMS

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AN EMPIRICAL INVESTIGATION INTO THE ECONOMIES OF SIZE FOR OKLAHOMA RURAL WATER SYSTEMS

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CHAPTER I

INTRODUCTION

Need for the Study

Increased regulations, relevant to the Safe Drinking Water Act (SDWA), have caused many concerns for water treatment facilities. The primary concern is the cost of compliance. These new regulations require monitoring for more contaminants and thus the cost of treatment and monitoring will increase. Currently, water treatment facilities must monitor and treat 83 contaminants. These new regulations increase the number of contaminants by 25 every three years. The increase in monitoring and potential treatment efforts may increase the cost of treating water. The means by which water treatment facilities assimilate these additional costs differ because of the quality of the raw water source, number of contaminants present in the water source, and the size of the facility. The additional costs to large treatment facilities can be spread over a large number of users. Rural treatment facilities often do not have this ability. Rural systems generally serve a small number of users and any additional costs in treating water increases the cost per user significantly more than for the larger facilities. Generally, Oklahoma rural water facilities serve a small number of users and these additional costs of compliance pose a massive challenge. It would be useful for Oklahoma rural water treatment facility decisionmakers or planners to understand how changes in output or quantity of treated water effect costs.

Background

Over the past quarter of a century, there have been tremendous advances made in the development of water treatment practices. Many of them have been adopted throughout the United States in response to the Federal Drinking Water Regulations (FDWR) along with the Safe Drinking Water Act (SDWA) and its 1986 Amendments. Currently, the SDWA applies to 200,000 public water systems serving 243 million Americans and its estimated cost of compliance is roughly $1.4 billion annually for public water systems (Auerbach, 1994). These adoptions of higher water quality standards are credited for reducing water-borne diseases such as cholera and typhoid. These adoptions have also reduced the number of incidences of other related diseases. These legislative actions or adoptions are caused by the potential threat to health standards regarding drinking water.

Water-borne diseases pose a tremendous threat to drinking water. These diseases are blamed for a large number of deaths every year and it is because of this type of health risk or threat that regulations such as the SDWA are passed by Congress and enforced by the Environmental Protection Agency (EPA) (USEPA, 1993). The ability to detect these diseases has increased because of the technological advances made in the monitoring equipment. Due to this increase in technology, regulatory forces are able to measure more accurately and more precisely the amounts of contaminants in water. EPA is responsible for assuring compliance to the FDWR and the SDWA. Due to these water regulations, EPA has increased its efforts to monitor water systems more closely. These efforts include increased monitoring and testing of water sources, recommendations for treatment technologies, and strict penalties if a water system is out of compliance. Monitoring and testing of contaminants is a continually growing effort and every three years the EPA will suggest to Congress another 25 contaminants that will require monitoring and potential treatment. The large number of contaminants pose a great concern to all water systems because the treatment costs of providing water may increase due to the new regulations. The primary concern is the cost of compliance.

The cost of compliance for water systems differs greatly due in large part to the size of the system and the number/variety of contaminants found in raw water sources. The larger the number of contaminants present within a raw water source, the more likely the treatment system will need better equipment to treat the raw water. All costs could be potentially impacted by the new regulations. However, the most dominant in terms of magnitude is capital cost. Capital costs are directly impacted as a new treatment facility may be needed. Operating and maintenance (O & M) costs may also be impacted because of the increased monitoring and treatment efforts. To meet the EPA's regulations, water systems may have to upgrade the existing facility or construct a new facility. Although all systems could have to increase monitoring and potential treatment efforts, some will have more difficulty in complying than others. Rural systems face the greatest challenge in meeting compliance because it is more difficult to spread the additional costs over fewer people. Also, rural systems do not have the borrowing capacity as opposed to larger systems. The ability to borrow is directly affected by the size of the system because loan repayment is based upon the number of users the system serves.

The size of a water system is defined by either the number of users the system serves or by the amount of water treated. For rural systems, the number of users served or amount of water treated is often very small. An exact definition of small is difficult as agencies define it differently. EPA defines a small system to be a system that serves a population of less than 1,000 people. Rural systems have a small number of users in their service area. For this reason, the additional capital and O & M costs will pose a much more challenging task to small rural systems versus larger urban systems. The difficulty exists because the additional costs will be spread over a smaller number of users. For small systems, the cost per user may be significantly higher than for larger systems which spread the costs over more users.

Rural Water Systems in Oklahoma

In the state of Oklahoma, there are 267 rural water districts, 24 rural water corporations, and 129 public work authorities. These 420 water systems have 299,133 meters in use and serve a rural population of 1,046,966 (Oklahoma Rural Water Association, 1995). These systems are small and their direct concern is the increased cost of treating water. The ability to spread costs over a larger number of people or output of water, is sometimes referred to as the economies of size. The economic condition known as economies of size has to do with the economic condition of what is happening (decreasing, constant, or increasing) to costs as output is expanded (Beattie and Taylor 1993). This economic condition is experienced by large systems because of the ability to lower or decrease the costs as output is increased.

Summary of Data

For the project, data were gathered from FmHA water district offices across the state of Oklahoma. Observations collected consisted of new water treatment plants constructed from 1990 through 1994. There were only 13 observations collected because of data restrictions on time and source of borrowing. The Oklahoma rural water systems observed in this study serve on average a population of 1,751 people. The systems use surface water sources and the average daily demand for water is approximately 506,000 gallons. Total daily capacity approximately equals 1.1 million gallons. The 13 treatment plants used three different types of treatment technologies. The treatment technologies observed are slow sand filtration, microfiltration and package plant.

Objectives

As decisionmakers are faced with short and long run decisions regarding changing or upgrading treatment facilities, it would be extremely useful to have information relative to costs of alternative treatment facilities. The overall objective of this study is to summarize the changes occurring with treatment facilities and to demonstrate how these changes impact costs for Oklahoma rural water systems. More specifically, the objectives are to:

1) identify the type of treatment used in Oklahoma rural water systems;
2) determine the capital investment for each treatment type;
3) identify total annual treatment costs for each system;
4) determine which measure of output for the empirical models is the best; and
5) test the hypothesis of economies of size.

Objective (1) and (2) will be accomplished by gathering data from FmHA financed rural water systems that built new water treatment facilities from 1990-1994. To accomplish objective (3), a model utilizing data from FmHA records is used to estimate operating and maintenance costs per treatment type. Objective (4) is accomplished by conducting Restricted Least Squares estimation procedures. Objective (5) will test the condition of economies of size using estimation procedures such as Ordinary Least Squares (OLS) in the form of an indirect cost function assuming the Cobb-Douglas and Translog functional forms. Before describing each objective and its respective method, detailed information relative to various water regulations, treatment technologies, treatment technology costs, and the economic theory relative to economies of size is presented.

CHAPTER II

CONTRIBUTION TO KNOWLEDGE

This chapter focuses primarily on four areas. These include: (1) water regulations, (2) treatment technologies, (3) treatment technology costs, and (4) the economic theory of economies of size. The water regulations segment explains the SDWA and other regulatory aspects. The treatment technology segment explains the treatment technologies used by the Oklahoma rural water systems in this study. The way O & M costs are estimated is also explained and all assumptions made are presented. The treatment technololgy costs segment discusses the factors effecting treatment costs. Finally, relevant economic theory is presented. In this segment, the economic theory provides a framework that links the theoretical concept of economies of size to the empirical tasks. This segment also reviews previous economies of size studies.

Water Regulations

Regulatory influence of any kind begins by people sharing a concern about an area of common interest and acting together to change it in some way. There is usually an existing problem and a regulatory action of some kind is desired to alleviate the problem. Health hazards often cause this type of regulatory action.

An example of this type of health hazard exists regarding drinking water. Health hazards such as cholera, water-borne diseases and chemical contamination are just a few requiring regulatory action. Because of these concerns regarding drinking water, Congress passed legislation to protect residents from health hazards found in drinking water. The health hazards regarding drinking water are not quantified in terms of the number of complaints about the quality of drinking water, rather they are quantified by the number of outbreaks of certain water-borne diseases and deaths in a year or over some other time period being measured. It is because of these deaths and outbreaks that regulatory powers such as Congress pass legislation to prevent or minimize the number of these incidences. One example of this type of legislation is the passage and 1986 amendments to the Safe Drinking Water Act (SDWA).

From 1975 through 1985, EPA regulated 23 contaminants in drinking water. These regulations are known as the Interim Primary Drinking Water Regulations (IPDWRs). In 1986, Congress amended the SDWA or the Public Health Service Act. These amendments required EPA to set Maximum Contaminant Goals (MCLGs) and National Primary Drinking Water Regulations (NPDWRs), including Maximum Contaminant Levels (MCLs) for 83 specific substances (USEPA, 1993). The 83 contaminants are listed in Table I which consist of 22 IPDWRs (except trihalomethane) plus 61 new contaminants. These amendments also require EPA to regulate 25 additional contaminants every three years. These additional contaminants for regulation were drawn from a Drinking Water Priority List (DWPL), also to be updated every three years. The DWPL is a compilation of unregulated chemicals known or anticipated to pose a public health threat. In addition, each compound

TABLE I

Contaminants Regulated Under The Safe Drinking Water Act

CONTAMINANT	MCLG (mg/l)	MCL (mg/l)	POTENTIAL HEALTH EFFECTS
Atrazine	0.003	0.003	Liver, kidney, lung, cardiovascular effects possible carcinogen (Group C)
Barium*	2	2	Blood pressure effects
Carbofuran	0.04	0.04	Nervous system, reproductive system effects
Cadmium*	0.005	0.005	Kidney effects
Chlorobenzene	0.1	0.1	Nervous system, liver effects
Chlordane	zero	0.002	Cancer (Group B2)
Chromium* (total)	0.1	0.1	Liver, kidney, circulatory system effects
Dibromochloropropane (DBCP)	zero	0.0002	Cancer (Group B2)
o-Dichlorobenzene	0.6	0.6	Liver, kidney, blood cell effects
cis-1,2-dichloroethylene	0.07	0.07	Liver, kidney, nervous system, circulatory system effects
trans-1,2-dichloroethylene	0.1	0.1	Liver, kidney, nervous system, circulatory system effects
Tetrachloroethylene	zero	0.005	Cancer
1,2-Dichloropropane	zero	0.005	Cancer (Group B2)
2,4-D*	0.07	0.07	Liver, kidney effects
2,4,5-TP	0.05	0.05	Liver, kidney effects
Ethylbenzene	0.7	0.7	Liver, kidney, nervous system effects
Ethylene dibromide (EDB)	zero	0.00005	Cancer (Group B2)
Epichlorohydrin	zero	TT	Cancer (Group B2)
Heptachlor	zero	0.0004	Cancer (Group B2)
Heptachlor epoxide	zero	0.0002	Cancer (Group B2)
Lindane	0.0002	0.0002	Liver, kidney, nervous system, immune system, circulatory system effects
Mercury* (inorganic)	0.002	0.002	Kidney, central nervous system effects
Methoxychlor	0.04	0.04	Developmental, liver, kidney, nervous system effects

* Indicates original contaminants with interim standards which have or will be revised.

TT Treatment technique requirement.

\+ \+ Action level = 1.3 mg/L.

\+ Less than 5% positive or > detections limit of 1 count/100 ml.

** Not on list of 83.

*** Regulation currently not in effect.

TABLE I (Continued)

Contaminants Regulated Under The Safe Drinking Water Act

CONTAMINANT	MCLG (mg/l)	MCL (mg/l)	POTENTIAL HEALTH EFFECTS
Nitrate*	10	10	Methemoglobinemia (blue baby syndrome)
Nitrite	1.0	1.0	Methemoglobinemia (blue baby syndrome)
PCBs	zero	0.0005	Cancer (Group B2)
Pentachlorophenol	zero	0.001	Cancer (Group B2)
Selenium*	0.05	0.05	Nervous system effects
Styrene	0.1	0.1	Liver, nervous system effects, possible carcinogen
Toluene	1	1	Liver, kidney, nervous system, circulatory system effects
Toxaphene	zero	0.003	Cancer (Group B2)
Xylenes (total)	10	10	Liver, kidney, nervous system effects
Lead and Copper			
Lead*	zero	TT +	Cancer (Group B2), kidney, central and peripheral nervous system effects
Copper	1.3	TT + +	Gastro-intestinal effects
Phase V			
(di(2-ethylhexyl)adipate	0.4	0.4	Reproductive effects
Antimony	0.006	0.006	Decreased longevity, blood effects
Beryllium	0.004	0.004	Bone, lung effects, cancer (Group B2)
Cyanide	0.2	0.2	Thyroid, central nervous system effects
Dalapon	0.2	0.2	Kidney, liver effects
Dichloromethane	zero	0.005	Cancer (Group B2)
1,1,2-Trichloroethane	0.003	0.005	Kidney, liver effects, possible carcinogen (Group C)
Dinoseb	0.007	0.007	Thyroid, reproductive effects
2,3,7,8-TCDD (Dioxin)	zero	0.00000003	Cancer (Group B2)
Diquat	0.02	0.01	Ocular, liver, kidney effects

* Indicates original contaminants with interim standards which have or will be revised.

TT Treatment technique requirement.

\+ + Action level = 1.3 mg/L.

\+ Less than 5% positive or > detections limit of 1 count/100 ml.

** Not on list of 83.

*** Regulation currently not in effect.

TABLE I (Continued)

Contaminants Regulated Under The Safe Drinking Water Act

CONTAMINANT	MCLG (mg/l)	MCL (mg/l)	POTENTIAL HEALTH EFFECTS
Fluoride*	4.0	4.0	Skeletal fluorosis
Phase I (Volatile Organics)			
Benzene	zero	0.005	Cancer (Group A)
Carbon Tetrachloride	zero	0.005	Cancer (Group B2)
p-Dichlorobenzene	0.075	0.075	Kidney effects, possible carcinogen
1,2-Dichloroethane	zero	0.005	Cancer (Group B2)
1,1,1-Trichloroethane	0.2	0.2	Liver, nervous system effects
1,1-Dichloroethylene	0.007	0.007	Liver, kidney effects, possible carcinogen (Group C)
Trichloroethylene	zero	0.005	Cancer (Group B2)
Vinyl Chloride	zero	0.002	Cancer (Group A)
Coliform and Surface Water Treatment			
Giardia lamblia	zero	TT	Gastro-enteric disease
Legionella	N/A	TT	Pneumonia like effects
Standard plate count	N/A	TT	Indicator of treatment effectiveness and water quality
Total Coliform*	zero	<5%+	Indicator of gastro-enteric infections
Turbidity*	N/A	TT	Interferes with disinfection, indicator of filtration performance
Viruses (enteric)	zero	TT	Gastro-enteric disease, respiratory disease and other diseases (e.g., hepatitis, myocarditis)
Phase II			
Acrylamide	zero	TT	Cancer (Group B2), nervous system effects
Alachlor	zero	0.002	Cancer (Group B2)
Aldicarb***	0.001	0.003	Nervous system effects
Aldicarb sulfoxide***	0.001	0.004	Nervous system effects
Aldicarb sulfone***	0.001	0.002	Nervous system effects
Asbestos (fiber >10um/l)	7MFL	7MFL	Possible carcinogen by ingestion

TABLE I (Continued)

Contaminants Regulated Under The Safe Drinking Water Act

CONTAMINANT	MCLG (mg/l)	MCL (mg/l)	POTENTIAL HEALTH EFFECTS
Endothall	0.1	0.1	Liver, kidney, gastro-intestinal effects
Endrin	0.002	0.002	Liver, kidney, heart effects
Glyphosate	0.7	0.7	Liver, kidney effects
Hexachlorobenzene*	zero	0.001	Cancer (Group B2)
Hexachlorocyclopentadiene	0.05	0.05	Kidney, stomach effects
PAHs (benzo(a)pyrene)	zero	0.0002	Cancer (Group B2)
Diethylhexyl phthalate	zero	0.006	Cancer (Group B2)
Picloram	0.5	0.5	Kidney, liver effects
Nickel	0.1	0.1	Liver effects
Oxamyl (Vydate)	0.2	0.2	Kidney effects
Simazine	0.004	0.004	Body weight and blood effects, possible carcinogen (Group C)
Thallium	0.0005	0.002	Kidney, liver, brain, intestine effects
(1,2,4-) Trichlorobenzene	0.07	0.07	Liver, kidney effects
Arsenic (Interim)			
Arsenic*	none	0.05	Dermal, nervous system effects
Disinfection By-Products (Interim)			
Total Trihalomethanes	none	0.10	Cancer (Group B2)

* Indicates original contaminants with interim standards which have or will be revised.
TT Treatment technique requirement.
+ + Action level = 1.3 mg/L.

\+ Less than 5% positive or > detections limit of 1 count/100 ml.
** Not on list of 83.
*** Regulation currently not in effect.

Source: USEPA, "Technical and Economic Capacity of States and Public Water Systems to Implement Drinking Water Regulations". Report to Congress, September, 1993.

regulated under the SDWA must be reviewed triennially to determine the continued adequacy of the MCLGs/MCLs. EPA divided the 83 compounds into groups and chose to regulate the groups in stages, based upon the availability of data and studies to develop the MCLGs and MCLs for each contaminant. These regulations are known as Phases I, II, III, IV, and V, with the exception of fluoride, which was regulated on April 2, 1986, and lead and copper, which were regulated on June 7, 1991. Phase III later became known as the radionuclides rule and Phase IV became known as the Disinfection-By-Products Rule (DBPR). Arsenic and sulfate dropped out of Phases II and V, respectively, and are being regulated separately. For each contaminant, monitoring requirements were promulgated, along with an MCG and MCL. These are presented in Table I for each contaminant.

Even though the SDWA does not require the EPA to develop national cost estimates for its regulations, EPA calculates these costs in accordance with Executive Order 12291, which requires Regulatory Impact Analyses for major regulations. The EPA is delegated the responsibility of providing viable and cost effective treatment technologies for small water systems to aid in meeting compliance standards. (USEPA, BAT Document). EPA developed the Best Available Technologies (BAT) document for small drinking water regulations. The BAT document lists 23 treatment methods for small water systems. Each method is described in terms of process descriptions, technology applications, design assumptions, estimated costs, and developed costs with actual process installations. The BAT document recommends a variety of treatment methods for small systems. However, the ones discussed below will only pertain to the types observed within the Oklahoma rural water system data set from FmHA (RECD).

The Oklahoma rural water systems observed in the FmHA data set (13 observations) are primarily made up of filtration technologies treating surface water only. The ones observed in the data set consist of slow sand filtration, microfiltration and some package plant treatments. Specifically, there were seven slow sand filtration, two microfiltration and four package plant treatment systems.

Treatment Technologies

The discussion to follow summarizes the treatment technologies found in Oklahoma rural water systems. More detailed information is provided in Appendix A. This appendix gives a more detailed analysis of each technology and how the costs are derived as well as listing all assumptions relevant to estimation procedures for O & M costs. Estimation procedures for O & M costs may seem overwhelmingly dominant throughout the discussion. However, these costs are the most difficult to estimate and wrong estimates could cause rural systems to choose an incorrect treatment technology. "One of the shortcomings experienced by the small communities is the underestimating of costs for maintenance and operating", (Moberg, 1976).

Slow Sand Filtration

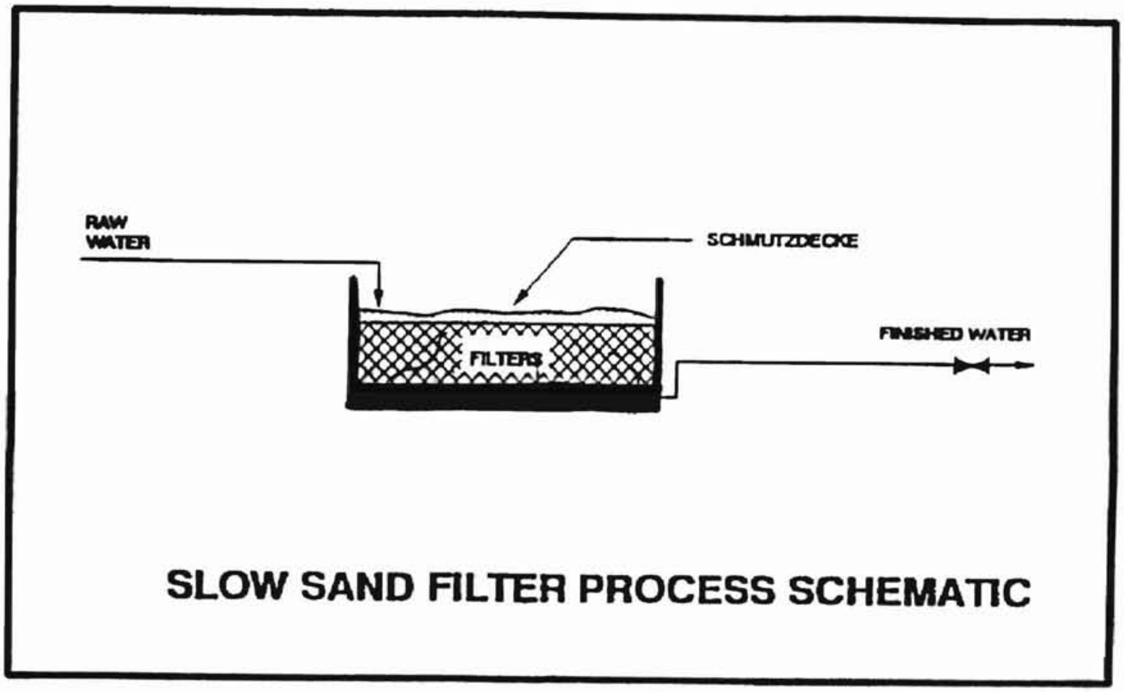
The Oklahoma observations in this study use surface water for each respective project. These observed technologies for treatment are highly dependent upon the quality of the surface water. Slow Sand Filtration (SS) is perhaps the oldest water treatment technique. SS is a very simple and inexpensive technology that is widely used by small systems because of the low maintenance costs. SS removes turbidity, microbes, bacteria and even giardia cysts. Figure 1 shows a schematic presentation of the SS method. The raw water is poured into the filter box and it first passes through a layer of gelatinous biological growth known as schmutzdecke. The water is pulled by gravity through the various layers of filters. The filters begin with the layer of schmutzdecke and are followed by various sizes of gravel. Once the water reaches the bottom of the filter box, the treatment is complete and the water is ready for distribution. All assumptions and detailed estimation procedures are explained when estimating the O & M values for the SS system.

Microfiltration

Microfiltration (MF) membranes were initially developed for sewage treatment. The largest scale use of this type of method is in the industrial market where it is used to remove solids from process juices and fluids as well as concentrate, sterilize, de-water, and treat wastewater. MF has been developed as an alternative technology for convential filtration and can be used as a

FIGURE 1

Schematic Presentation of Slow Sand Technology



SLOW SAND FILTER PROCESS SCHEMATIC

Souce: USEPA, "Very Small Systems Best Available Technology (BAT) Cost Document". September, 1993.

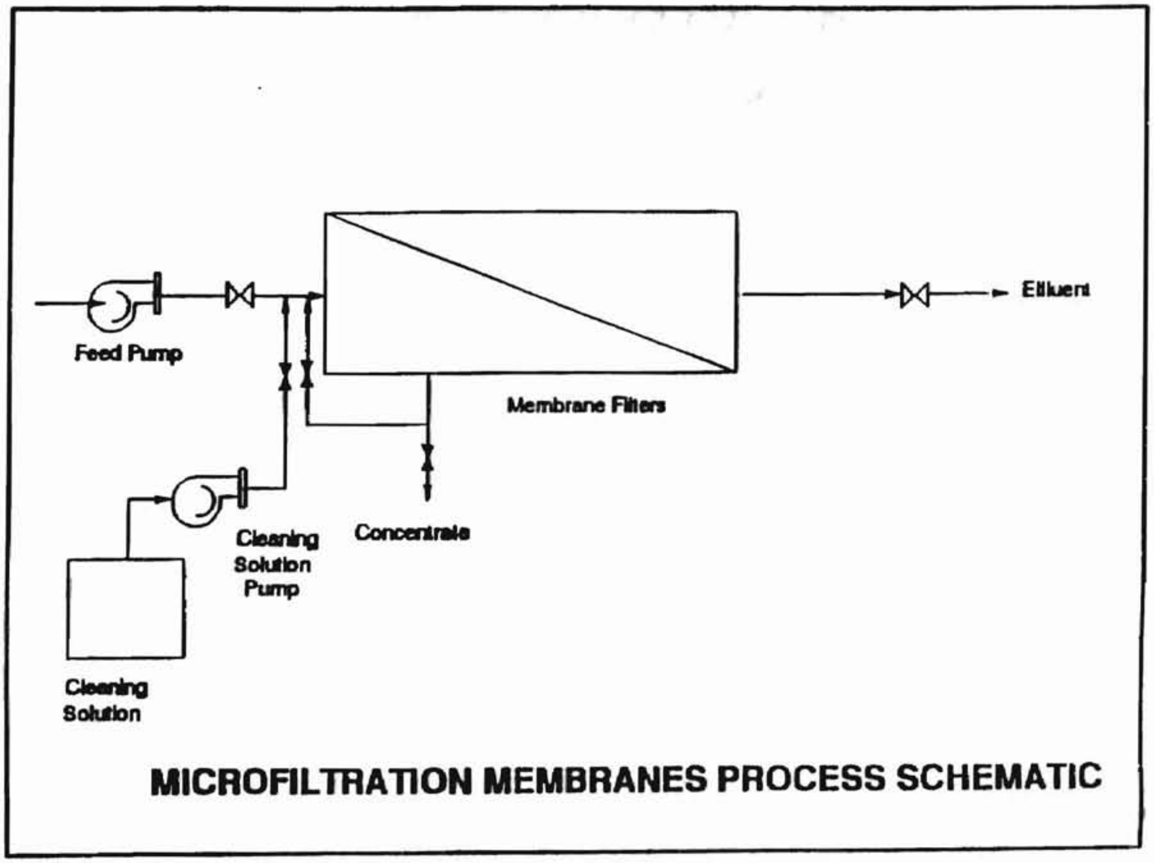
pretreatment process for other technologies. MF has the largest pore size of the membrane processes. This treatment technology can remove synthetic organic chemicals, organic matter. MF is best for removing particles, but does not remove dissolved inorganics, such as carbonate, sulfate and metals. The organics removal can be enhanced by adding a coagulant. Figure 2 shows a schematic presentation of the microfiltration system. The feed pump injects the water through the main water line where the cleaning solution is added and is flushed into the membrane filters. The water travels through the filters and the particles are tied up with the cleaning solution and flushed out as concentrates. The water is then ready for distribution. The double arrows indicate the systems ability to back flow the water in case the treated water does not meet MCLs. MF is used because of its relatively low maintenance requirements. MF is most attractive because no chemical sludge residuals are found when using this method.

Package Plants

Package plant treatments consist of a variety of treatments options. The package plant itself is shipped to the site in a pre-fabricated form ready to assemble and use. The technology used in the Oklahoma data set is ion exchange. A schematic presentation of an ion exchange process is provided in Figure 3. This technology relies on exchange resins to remove ions from water. Synthetic ions are used to replace ions in the feed water with ions of similar charge fixed to a resin matrix. To be effective, ion exchange must be reversible

FIGURE 2

Schematic Presentation of Microfiltration Technology



Source: USEPA, "Very Small Systems Best Available Technology (BAT) Cost Document". September, 1993.

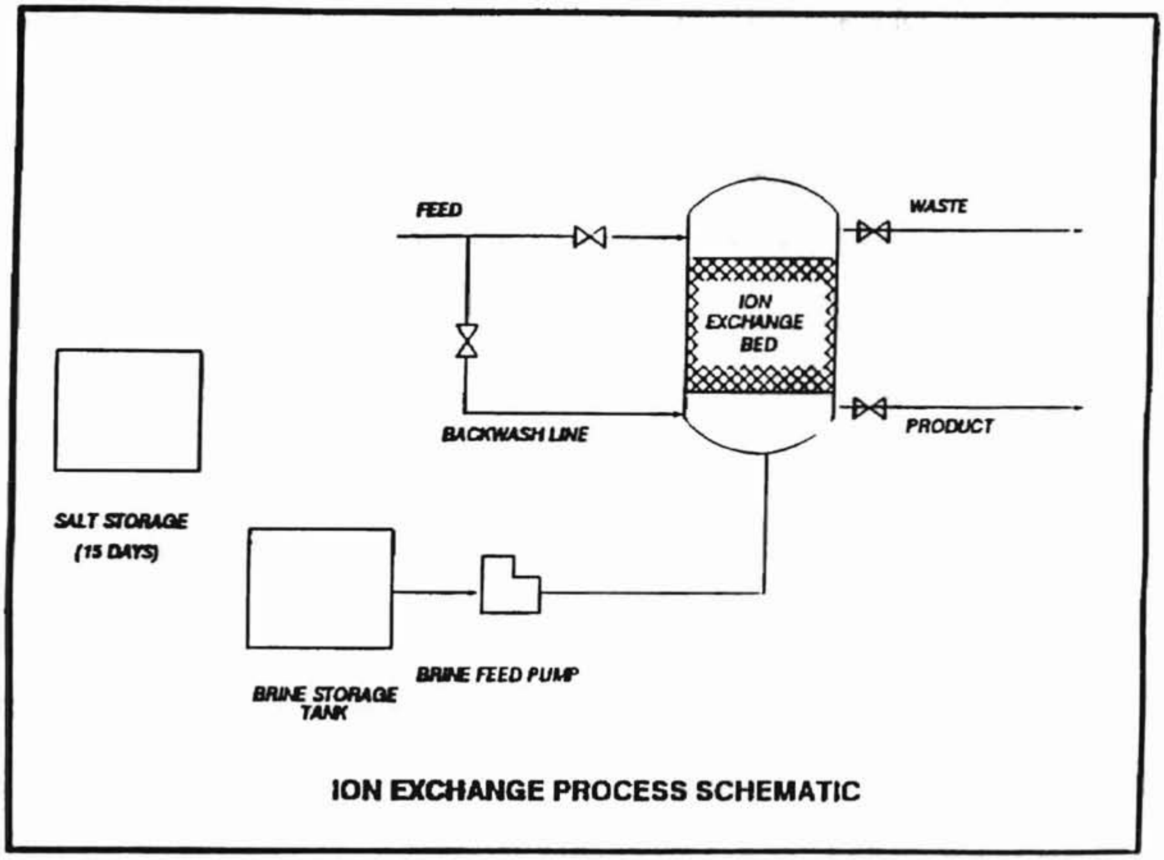
and selective to which ions are removed. The resin matrix contains generally insoluble solids comprised of fixed anions or cations capable of exchanging, through electrostatic attraction, with similarly charged ions in the raw water. Cations are positively charged ions, and anions are negatively charged. The efficiency of ion exchange is affected by several factors such as ion selectivity, resin capacity, regenerations requirements and mode of operation. Resin capacity describes the total amount of ions that can be exchanged per volume of resin. A high capacity resin is preferred, since it takes up less area. These are more expensive. The regeneration process displaces the ions exchanged from the raw water, and restores the resin's exchange capacity. Because a fixed bed mode for ion exchange is the simplest, it is recommended for small systems. This mode uses a fixed bed which is back washed and regenerated periodically. Since the costs of treatment are critical for small water systems, a discussion of capital and O & M costs is provided.

Treatment Technologies Costs

The cost of treatment on an annual basis for any system is made up of many components. They range from the initial capital investment (equipment, land etc.) to the every day maintenance requirements. The cost of treatment depends upon many other items. Some of these items are the type of raw water source, contaminants present, and the overall quality of the raw water. The review of the BAT document reveals the way in which both annual costs of treatment are derived along with their assumptions. The BAT document uses

FIGURE 3

Schematic Presentation of Ion Exchange Process Technology



Source: USEPA, "Very Small Systems Best Available Technology (BAT) Cost Document". September, 1993.

many equations to estimate both annual capital and O & M costs. The equations are in log linear form. Appendix A lists the assumptions the BAT document made to estimate both costs as well as lists a more detailed description of each treatment technology. The annual O & M estimates generated by the Cornell model (which uses the BAT equations) were used along with empirical data for Oklahoma rural systems to estimate annual cost of treatment for each system within the Oklahoma data set. A detailed explanation of the estimates for annual O & M and capital costs are presented in Appendix A. Although Appendix A offers an explanation of costs and assumptions, there needs to be a framework in which these costs can be observed in the short and long run. Also, to test the condition of economies of size, a framework relevant to the theory of cost is explored.

Economic Theory

The economic theory segment focuses on four areas. These include: (1) the theoretical concept of economies of size, (2) a review of previous research on economies of scale or size for water treatment facilities, (3) an explanation of the theory of cost regarding economies of scale or size , and (4) a discussion of the empirical models which estimate annual costs for Oklahoma rural systems.

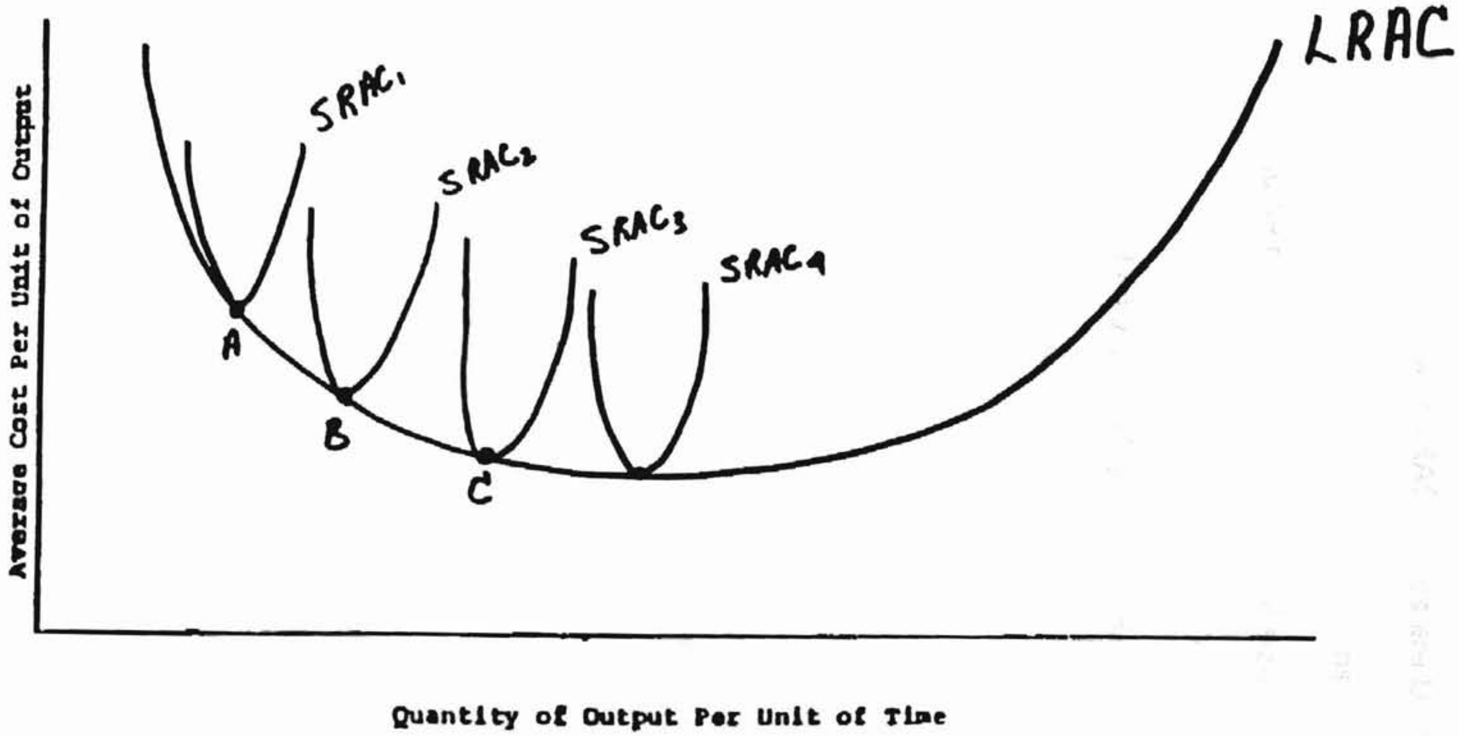
Theoretical Concept of Economies of Size

Before discussing economies of size or scale, a distinction between the two concepts is needed. Economies of scale measures the proportional change in output due to a one percent change in all inputs. Economies of size relates to the proportional change in output as factors are expanded in least-cost proportions along an expansion path. Only in the case of homothetic, homogeneous production functions such as the Cobb-Douglas is the expansion path a linear ray out of the origin. In this case, returns to scale are equal to returns to size. If the production functions are non-homothetic, the two concepts are not equivalent. When discussing the characteristics of an average cost curve (decreasing, constant or increasing), as factors are increased in least-cost proportions, the appropriate term to use is (decreasing, constant or increasing) returns to size.

Economies of size or scale involve two different time contexts which are the short and long run. In the short run, physical factors such as water treatment plant machinery are fixed. The associated costs of these factors remain unchanged (fixed) for the production period. In the long run, enough time is available for expanding any or all of the physical factors. In this context, these fixed costs become variable. Many short-run average cost (SRAC) curves are illustrated in Figure 4. "This is really far from enough and many curves could be drawn between each of those shown", (Ferguson and Gould, 1975). These many curves form the long-run average cost (LRAC) curve. Output is represented as MGD of treated water. At point A, the average cost per unit is significantly higher than for point B. At point B, the average cost per unit is significantly higher than for point C. As output is expanded the average cost per unit decreases. Point A represents a small water treatment facility and point C

FIGURE 4

Long-Run and Short-Run Average Cost Curves



represents a larger water system. Both SRAC and LRAC curves are U-shaped. However, the reasons why are different. "LRAC are U-shaped if firms become successively more efficient up to some particular size or range of sizes, and if they then become successively less efficient as the range of plant sizes from very small to very large is considered", (Leftwich, 1970). "SRAC are U-shaped because the decline in average fixed cost is ultimately more than offset by the rise in average varaible cost", (Ferguson and Gould, 1975).

Previous Research on Economies of Scale or Size

In 1958, Orlob and Lindorf, examined treatment costs to determine its relationship to the cost of surface water transportation, reclamation of wastwaters, groundwater recharge, and any other alternatives available for increasing water supply in California. The theoretical cost function was a function of design capacity. The construction cost function was theorized to be a function in the form of:

(1) $C = \alpha\, Q_n^{\beta}$

where C is the total capital cost of a complete water treatment facility in thousands of dollars, Q_n is the design capacity of plant in million gallons per day (MGD), and α, β are constants. Estimation of the equation generated the following relationship:

(2) $C = 257\, Q_n^{0.67}$.

The value of $\beta = .67$ implies that economies of scale existed in treatment plant construction because if equation (2) is divided by Q_n, the exponent of Q_n is less than O. Unit cost therefore decreases with increasing Q_n or capacity, illustrating economies of scale.

Stevie and Clark (1982), examined the cost structure and financial problems of small water systems and provided estimates of the costs that small water systems incurred in meeting NIPDWR requirements. "The majority of water systems are small and the smaller ones tend to have more quality problems. Small systems (those that supply fewer than 10,000 people) supply more than 95 percent of the nation's community systems but represent less than 25 percent of the population". This article also found that economies of scale did exist. This study also identified the additional costs of add-on technologies such as ion exchange and activated alumina.

Empirical applications of the indirect cost function approach have not only focused upon using the CD functional form, but other more flexible forms have been employed for empirical tasks as well. An example is the Translog function. Christensen and Green (1976) used this flexible functional form for the electric utility industry; Bhattacharyya (1994) for large water systems; and Deller and Halstead (1994) for provisions of rural roads. Because of the complexity of the Translog function, there exists no closed-form relationship between the cost and production function. This may be inconvenient from a theoretical standpoint, but it does not pose any empirical problems. "All important economic concepts under the assumption of cost minimization, such as elasticities of input substitution, factor demands, and economies of size can be derived from the cost or the production function" (Shephard, 1953).

Theory of Cost

To connect the relationship between theory and empirical work, a theoretical framework is needed relating production to costs. For this, a production function for water needs to be established. The production function for water is of the form:

$$(3) \quad q = A X_1^b X_2^c$$

where q is the quantity of water, X_1 and X_2 are inputs such as labor and capital, A is a constant, and b and c are parameters of the function. This can be viewed as a particular treatment process and q represents the quantity of water treated (e.g. average daily demand or flow). This type of functional form is known as the Cobb-Douglas. The production elasticities are parameters b and c. The sum of the production elasticities provide an estimate of the relative change in output as inputs are increased simultaneously by one percent. Thus, the sum of the production elasticities has implications for the relative change in cost as output changes. As seen below, the indirect cost function derived from this production function is an exponential function of output and input prices. To derive the indirect cost function a discussion of the lagrangean (LF) function is needed.

$$(4) \quad LF = r_1 X_1 + r_2 X_2 + \lambda [q^o - A X_1^b X_2^c],$$

where the first two terms on the right-hand side of the equation represent each input, X_i, multiplied by its price, r_i. The sum of the two terms is variable cost. In the LF framework, the variable costs are constrained by a given level of output denoted as q^o. The LF framework provides a way to find the minimum cost levels of the two inputs to produce a given quantity of water. This is done by solving first-order conditions for the minimization problem, solving for input demands and substituting them back into the cost function. The substitution causes the indirect cost function to be a function of output and input prices. The first step in deriving this indirect cost function is to solve for first order conditions for a minimum regarding this constrained optimization problem. The first order conditions are:

(5) $\partial LC/\partial \lambda = q^o - A X_1^b X_2^c = 0,$

(6) $\partial LC/\partial X_1 = r_1 - \lambda bAX_1^{b-1} X_2 = 0,$ and

(7) $\partial LC/\partial X_2 = r_2 - \lambda c A X_1^b X_2^{c-1} = 0.$

Solving equations (6) and (7) for λ, and equating the expressions, yields:

(8) $r_1 / [bAx_1^{b-1} X_2^c] = r_2 / [c AX_1^b X_2^{c-1}].$

This expression simplifies to:

(9) $X_2 = X_1 [cr_1 / br_2],$

and this expression is the equation for the expansion path for a firm with a CD production function (i.e. one that is linear in logarithms) facing fixed prices. This expression is then substituted into equation (3) and the demands for the two inputs are derived. These demands are then substituted into the equation listed below:

(10) $C = r_1 X_1 + r_2 X_2$,

yielding the indirect cost function, which has only input prices and quantity as arguments. To evaluate relative costs of different technologies, it is necessary and convenient to assume prices are fixed. Under these fixed conditions, the indirect cost function can be written as :

(11) $C = [q^o]^{1/(b+c)} [A]$,

where A becomes a constant. This derivation allows the expression to be written as a constant multiplied by output raised to the power $1/(b+c)$, where b and c are the elasticities of the production function with respect to the two inputs. The production elasticities with respect to the two inputs provides an insight into the economic concept of returns to scale. If $1/(b+c) > 1$ then the production function would exhibit increasing returns to scale. Also, in equation (11) the elasticity of cost with respect to q^o is $1/(b+c)$. Therefore, if $(b+c) > 1$, then as output increases by one percent, cost increases by less than one percent because $1/(b+c) < 1$. If the production function exhibits decreasing returns to scale, *(e.g.* $(b+c) < 1$*)*, then cost rises by more than one percent as output is increased by one percent. Cost increases in proportion to output if $(b+c) = 1$ and the production function is said to exhibit constant returns to scale. Expressions of marginal and average cost can now be written. From equation (11) average cost is shown by:

(12) $AC = C / q^{o}$, which would yield,

$$= [q^{o}]^{1/(b+c) - 1} [A].$$

If the reciprocal of the sum of the production elasticities is less than unity, then average cost is declining everywhere. Marginal cost is:

(13) $MC = \partial C / \partial q^{o} = (1 / (b+c))\, C / q^{o}$.

If the reciprocal of the sum of the production elasticities is less than unity, then marginal cost lies every where below average cost. The magnitude of AC and MC have important characteristics for the empirical tasks ahead. Before discussing the empirical model, a distinction between economies of scale and economies of size needs to be made. Economies of scale measures the proportional change in output due to a one percent change in all inputs. The returns to size relates to the proportional change in output as factors are expanded in least-cost proportions along an expansion path and only homothetic or homogeneous production functions such as the CD is the expansion path a linear ray out of the origin (Beattie and Taylor, 1993). In this case returns to scale are equal to returns to size. In the case of non-homothetic functions, the two concepts are not equivalent. So, when referring to average cost declining as factors are increased in least-cost proportions, the correct term is increasing, decreasing or constant returns to size.

Empirical Model

For fixed input prices, it is possible to take the logarithms of both sides of equation (11). This would yield an equation of the form:

(14) $\ln C = \ln A + 1 / (b+c) \ln [q^{O}]$,

where ln C would represent the total annual cost of water treatment, ln A is a constant, b and c are parameter estimates, and q is defined as the population served. The logarithmic transformation of equation (9) is linear in the parameters ln A and 1 / (b+c). Given the annual cost of treatment and output levels, the parameters can be estimated using ordinary least squares (OLS). For policy implications, output is defined as the number of population served for each project within the data set. This is also the measure used by the EPA and others to classify systems by size. Testing the economic condition of economies of size is obtained by evaluating the coefficient on $\ln q^{O}$. Therefore, the null and alternative hypotheses are:

Ho = Diseconomies of Size Exist, and
Ha = Economies of Size Exist.

A simple t test will be performed upon the $\ln q^{O}$ coefficient. If significant at the 5% or 10% level of confidence, then economies of size do exist and therefore the null hypothesis would be rejected. The magnitude of the economies of size will be determined by the 1 / (b+c) coefficient. If equal to one then constant returns to size are present; if equal to less than 1, then decreasing returns to size are present and if greater than 1, then increasing returns to size are present.

To test the economic condition of economies of size a more flexible functional form can be used. An example is the Translog functional form where the returns to scale can vary with output. Significance of the economies of size condition as well as implications are discussed in Chapter IV. Before proceeding to the empirical estimates, the data used for the analysis are discussed in Chapter III.

Chapter III

DESCRIPTIVE ANALYSIS OF DATA

To fully understand the data, it is useful to analyze each variable and identify any relationships that are present within the variables. This chapter presents a descriptive analysis of the data. The analysis focuses upon three areas which include: (1) general data characteristics, (2) variables, and (3) data classifications.

General Data Characteristics

The data were collected from Farmers Home Administration (FmHA) files. FmHA has been reorganized and its new name is Rural Economic and Community Development (RECD). FmHA (RECD) was chosen because of data availability, reliability and consistency. The data collected consists of 13 observations. Each observation is a rural town or water district in Oklahoma that has borrowed money to build a new water treatment plant. The observations collected cover a four year period (1990-1994). The data are of cross sectional type because each observation is a snapshot in time (1990-1994). By definition the data can not be considered time series data unless the same observations were collected year to year from 1990-1994. The number of observations were expected to be much higher, but due to data restrictions such as the type of borrowing, there were only 13.

Each entity borrowing money through FmHA is required to fill out a set of forms that aids FmHA in determining the grant and loan amounts. For each town or water district in the data set the following forms were collected: (1) Project Summary (1942-45), (2) Grant Determination (1942-51), (3) Project Fund Analysis (1942-14), (4) Federal Assistance (424.1), and the (5) Operating Budget. The engineering report was reviewed to obtain information on other variables. The data consists of two types of sampling extremes. First, there are rural towns/water districts which serve a very small population (<1000) borrowing a significant amount of money (>$1 million) to build a new water treatment plant. Second, there are rural towns/water districts made up of a larger population (>2000) borrowing only a small amount of money (<$350,000). The primary reason for this is due to the type of treatment being installed and the water source they are using. The cost of each project is dependent on what items have to be installed for each chosen treatment technology. The type of treatment technology chosen has to meet two different goals. First, the technology has to remove the contaminants from the respective water source. Second, the rural town or water district must choose a technology that will meet their respective treatment goal and be cost effective. The type of treatment and their respective costs will be discussed later in Chapter IV in the treatment technology section. This type of sampling could cause skewness, non-normality of error terms, heteroscedasticity or some combination of all three. These types of problems, if encountered, will be corrected for later in Chapter IV when the statistical estimation procedures are discussed.

Variables

This section is devoted to explaining the variables found within the FmHA data set and their respective derivations. The explanation of these variables in the data set will aid in understanding the trend analysis section as well as the variables being used in the estimation procedures. The variables of interest include: population served by project, average daily demand (ADD), average daily production (ADP), total project or capital costs to be annualized and estimated annual O & M costs per treatment type. These variables come from the FmHA forms listed above or the engineer's report except for the estimated annual O & M costs. Those are generated by a computer simulation model to be discussed later.

Because the data are cross-sectional in nature, there needs to be a procedure used to compare the cost variables across time. Some variables require a transformation to compare values within the data set across time (1990-1994) and also to conduct mathematical estimation procedures, such as Ordinary Least Squares (OLS). The variables that need to be transformed are capital costs or total project costs and O & M costs. Capital costs represent the total amount of money borrowed by the rural town/water district to build their respective treatment facility. To compare costs across time (20 year life of facility), the capital cost must be annualized over the life of the facility using an appropriate interest rate (8%). By annualizing capital costs, an annual cost per treatment type can be calculated by adding annual capital costs with annual O & M costs. However, annual O & M costs are not so easily derived.

Within the FmHA data set is an O & M cost figure estimate, but it is for the entire system and is not the marginal O & M cost of adding a specific type of treatment for the respective rural project/water district. Due to the complexity in determining annual O & M costs per treatment type by FmHA, the data set lacks this important component. To estimate annual O & M costs per treatment type, a computer simulation model was employed. The model was developed at Cornell University and can be used to estimate many costs, but for this study only O & M estimates are used. The model used cost equations from the Best Available Treatment Technology Document (BAT) for small water systems, issued by the Environmental Protection Agency (EPA), to determine the cost of treatment for a wide variety of contaminants. These technologies and their respective cost equations are built into the computer model and only certain parameters are needed to determine the estimated O & M costs per treatment type. The parameters needed include ADD, ADP, and treatment type. These parameters are found within the FmHA data set from the engineer's report. The data found in Table II illustrates these three variables sorted by town/water district along with their respective annual costs. Data in Table II clearly show the majority of the treatment types are slow sand filtration. The other treatment types include

TABLE II

Oklahoma Rural Water System Characteristics

						Annual ($1992)		
Town	Date	Treatment	ADD	ADP	Population	O & M	Capital	Total
Wagoner	1990	Slow Sand	2,000,000	1,000,000	4,500	$330,100	$142,592	$472,692
Jay	1990	Microfiltration	1,000,000	300,000	624	73,941	183,389	257,330
Muskogee	1990	Package Plant	1,000,000	450,000	1,450	332,150	44,917	377,067
Stilwell	1990	Slow Sand	2,000,000	1,000,000	800	336,399	123,414	459,813
Coweta	1990	Slow Sand	3,000,000	900,000	3,500	446,779	187,153	633,932
Westville	1991	Package Plant	300,000	80,000	850	60,900	188,834	249,734
Hulbert	1992	Package Plant	1,000,000	650,000	2,119	478,450	207,015	685,465
Vian	1992	Microfiltration	1,500,000	500,000	1,250	113,229	68,241	181,470
Stuart	1993	Package Plant	700,000	225,000	1,224	19,950	134,231	154,181
Langston	1993	Slow Sand	300,000	165,000	448	36,939	49,636	86,575
Crowder	1993	Slow Sand	1,500,000	680,000	2,500	184,695	79,469	264,164
Barnsdall	1994	Slow Sand	500,000	350,000	1,700	61,565	97,855	159,420
Ketchum	1994	Slow Sand	350,000	180,000	1,800	65,871	175,206	241,077

microfiltration along with some package plant treatments. The treatment type chosen for each project is based upon the contaminants present and cost. The type of water source also plays a very important role in determining the type of treatment needed. The observations listed in Table II receive water from surface sources. Some are very clear and have few contaminants and some are very poor requiring more filtration and disinfection, hence a higher cost for the rural town/water districts receiving their water from poor surface sources. Before explaining the data transformations, a better understanding of the water variables are needed (ADD, ADP) as well as what is meant by population served.

The population served variable comes from the FmHA project summary form. This variable is the number of people served by the proposed project for each respective rural town/water district. The two water variables are ADD and ADP. These variables were found in the engineer's report for the respective town/water district. ADD is the average daily demand for water within the rural town/water district. It is the total amount of water on a daily basis demanded by the respective rural town/water district. ADP is the average daily production of treated water that can be distributed for consumption. When building a new treatment plant facility, the system size always exceeds the system's current demand to allow for growth. This is why ADP values in Table II are always larger than ADD values. The estimates of annual O & M costs are transformed using a construction cost index that converts the O & M costs to a 1992 dollar value. For this reason, the capital costs are also converted using the same index to an annual basis. The construction cost index comes from an Engineering News-Record report published by McGraw-Hill and the index used for each year (1990-1994) are the yearly averages. The average yearly values for 1990, 1991, 1992, 1993, 1994 are respectively 4732, 4835, 4985, 5210 and 5408. These yearly average values are used to calculate an index using 1992 as the base year. The formula for calculating an index is shown below as equation (15).

(15)   Current - Base / Base x 100 = Index

By applying this formula the construction indices for 1990, 1991, 1992, 1993, and 1994 are derived. These indices are used to convert the cost data to 1992 dollars. The transformation enables the calculation of capital and O & M costs. The discussion below focuses upon the observed Oklahoma Rural water systems. The discussion covers both (1) Oklahoma Rural characteristics and (2) descriptive statistics.

Oklahoma Rural Water System Characteristics

On average, the type of system built between 1990-1994 served 1751 people, had a 1.16 million gallon production capacity, and produced 506,154 gallons annually. The average capital investment was roughly $1.2 million dollars when annualized over 20 years at an 8% interest rate, the annual capital amount was $129,381. The estimated O & M costs, on average across treatment types, was roughly $195,459. This value was only the amount of O &

M costs for the specified treatment technology and does not include the total system operating and maintenance costs. On average, the systems in the data set spent roughly $324,840 on total annual costs (annual capital plus annual O & M). On an aggregate basis, approximately $16.5 million was invested between 1990-1994 to build new treatment plant facilities in Oklahoma rural with an annual O & M cost of $380,000. The $16.5 million annualized over 20 years at an 8% yields an annual capital cost of $1.68 million. These investments in new treatment plants served roughly 22,000 people in the state and the systems had the potential to produce 15.15 million gallons a day. However, the systems only demand 6.58 million gallons. The difference between supply and demand of treated water is for growth and expansion. This type of growth or expansion is estimated by the engineers. As data in Table III illustrates, there is a tremendous amount of money being invested in new treatment plant facilities and treatment technology. It is important to understand what might cause costs to change over time. For this reason, a more detailed analysis of the descriptive statistics associated with the observed Oklahoma Rural water systems is useful.

Oklahoma Rural Water System Descriptive Statistics

Data in Table III show some descriptive statistics for the observed Oklahoma Rural water systems. Data in Table III focus upon relevant variables. They include population served, ADD, ADP, estimated annual O & M costs, and annual capital costs, total project or capital costs, and total annual

TABLE III

Oklahoma Rural Water System Descriptive Statistics

Statistic	Population	ADD	ADP	Total Capital	Annual ($1992) Capital	O & M	Total
Mean	1,751	506,154	1,165,385	$1,270,281	$129,381	$195,459	$324,840
Standard Error	326	93,235	224,849	154,972	15,784	46,016	52,079
Median	1,450	450,000	1,000,000	1,317,900	134,231	113,229	52,079
Standard Deviation	1,177	336,162	810,706	558,761	56,911	165,913	187,773
Kurtosis	1.31	-.95	.58	-1.49	-1.33	-1.49	-.35
Skewness	1.27	.55	.95	-.20	.59	-.20	.81
Range	4,052	1,020,000	2,700,000	1,591,500	162,098	458,500	598,889
Minimum	448	80,000	300,000	441,000	44,917	19,950	86,575
Maximum	4,500	1,100,000	3,000,000	2,032,000	207,015	478,450	685,465
Sum	22,765	6,580,000	15,150,000	16,513,649	1,681,952	2,540,968	4,222,919

costs. Some type of skewness and kurtosis is present in all the variables found in Table III. Skewness is defined as a measure of the asymmetry of a distribution and kurtosis is a measure of the thickness of the tails of the distribution (Greene, 1993). For a symmetric distribution, skewness would be equal to zero. To be positively skewed, the mean would exceed the median, which is the case for population, ADD, ADP, annual O & M, and total annual costs. To be negatively skewed, the median would exceed the mean. This condition describes the variables total capital and annual capital costs. Proof of this condition for these two variables can be demonstrated by observing their mean and median. For total capital, the mean is 1.27 million and the median is 1.317 million. This is proof of negative skewness. Also, as the amount of skewness increases negatively or positively, kurtosis moves accordingly. As the amount of skewness increases so does the amount of kurtosis, because the distributional shift moves the distribution to the left or to the right, therefore increasing the tail area associated with each move. Specifically, the population variable has a mean of 1,751 and a standard error of 326. The mean is larger than the median, hence this variable has positive skewness. The range (calculated by taking the largest value minus the smallest) is 4,052 with the smallest population being 448 and the largest 4,500.

The ADD variable has a mean of 506,154 gallons with a standard error of 93,235 and it has positive skewness. The range is 1,020,000 with the smallest ADD value being 80,000 gallons and the largest is $1.1million. This large difference reflects the increased demand of more people. Observing the ADP variable gives a more detailed analysis as to how many gallons on average could these systems produce on a daily demanded basis. ADP has a mean value of 1,165,385 with a standard error of 224,849 and is positively skewed. The range is 2.7 million gallons with the minimum being 300,000 and the maximum is 3,000,000. ADP values reflect total design capacity of a system since it represents the total amount of water that is able to be treated and distributed. The average treatment plant total cost of capital is $1.27 million and this variable is negatively skewed with a range of $1.591 million. The mean for annual capital costs is $129,381 with a standard error of $15,784 and a range of $162,098 and is negatively skewed. The average annual cost of O & M for all treatment technologies is $195,459. This represents the amount of cost attributed to the technology chosen on average across the data set. The standard error for this variable is $46,016 with a range of $458,500. One of the more important variables is total annual cost. On average total costs are $324,840 with a standard error of $52,079. An important observation at this point is that the average annual O & M values exceed the average capital values. This is represented because small system costs are being observed where labor is dominant versus being capital dominant. For systems to be able to endure the increased regulations, both cost components will have to be kept at a minimum. This descriptive statistical segment provides some insight into the Oklahoma rural Water System statistical properties. This insight aids in understanding the variables individually and any potential impact upon one another. To understand the more specific effects of the variables on annual capital, O & M, and total costs, the discussion below segments the data by system and explanatory power.

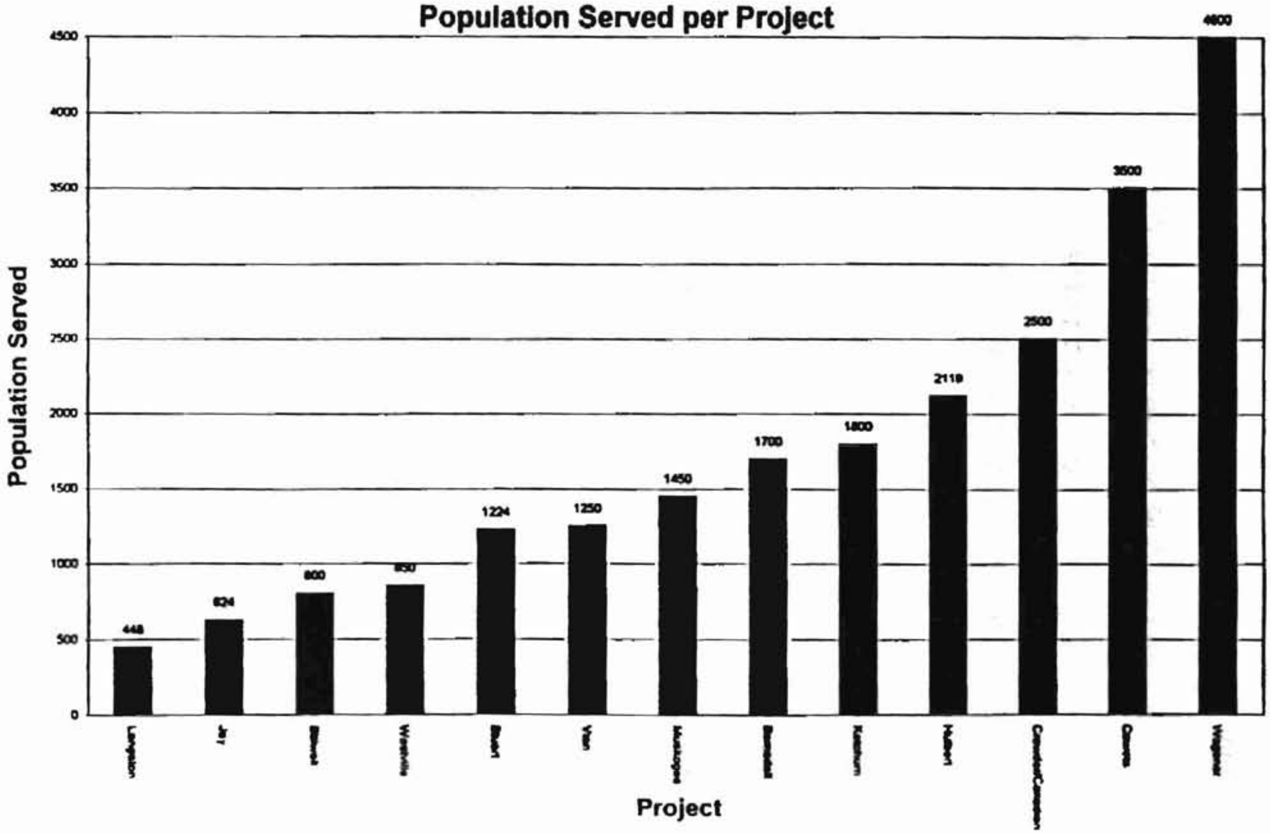
Data Classifications

This segment focuses on two classifications. These classifications are (1) system, and (2) explanatory power. The system classification discusses such aspects as population served, ADD and ADP per project. The explanatory power or R-square classification discusses the variables explanatory power relative to total annual costs.

System

Figure 5 begins the system classification analysis by observing the population served per project. Project is defined as being either a rural water district or an entity. As Table III indicated, the range of population served is 4,052. Langston has the smallest population served at 448 and Wagoner has the largest at 4,500. If the population served range is segmented into frequencies of <1,000, 1,000-2,000 and >2000, then the resulting frequencies would be 4, 5, and 4 respectively. The segmentation into frequencies illustrates each segment is evenly represented within the data set. Because of the large population served by Wagoner and Coweta, the mean of the population is misleading. The median would be a better value to observe because the median is not subject to skewness due to large numbers. It is simply the midpoint of the

FIGURE 5
Population Served per Project



population data. This type of range between large observations and small ones, relative to each variable of interest, will be present throughout.

ADD per project is presented in Figure 6. Coweta along with Wagoner and Stilwell have the highest ADD values exceeding 900,000 gallons. This is due to in large part the demand for water based upon the population served sizes of the systems. At the other end of the range, the projects with the smallest populations (Jay) have on average the lowest ADD values. Because of this relationship, it is hypothesized that the ADD for water is a function of population served. This also holds true for ADP. ADP per project is observed in Figure 7. Wagoner and Stilwell are exceeded by Coweta for ADP values. Coweta's facility is capable of ADP of 3,000,000. The difference between Coweta's ADD value and ADP is explained by the anticipated future expansion and or growth of the system. If Figure 6 ADD values are compared to Figure 7 ADP values, then the amount of growth for each project's system can be observed. This amount is estimated by the engineer.

Data in Figure 8 show O & M costs per project. The hypothesized relationship between ADD and population served does not apply in the same manner for costs. Hulbert has the highest O & M costs at $478,450 and Coweta has the second highest costs at $446,779. This is attributed to the type of treatment the plant is using. This is also explained by the quality of the water source at each location. For Coweta, the quality is not as good as Wagoner's source and it requires more detailed treatment. This more detailed

FIGURE 6

Average Daily Demand per Project

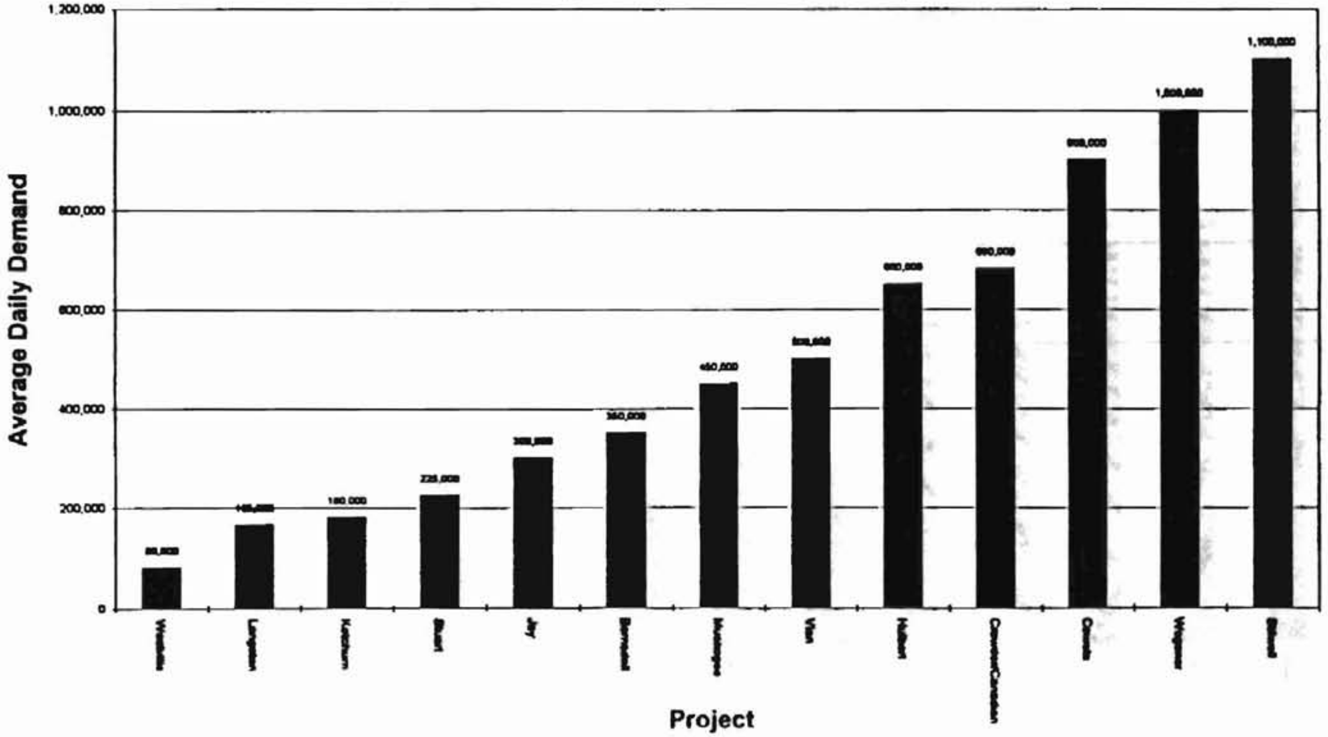


FIGURE 7

Average Daily Production per Project

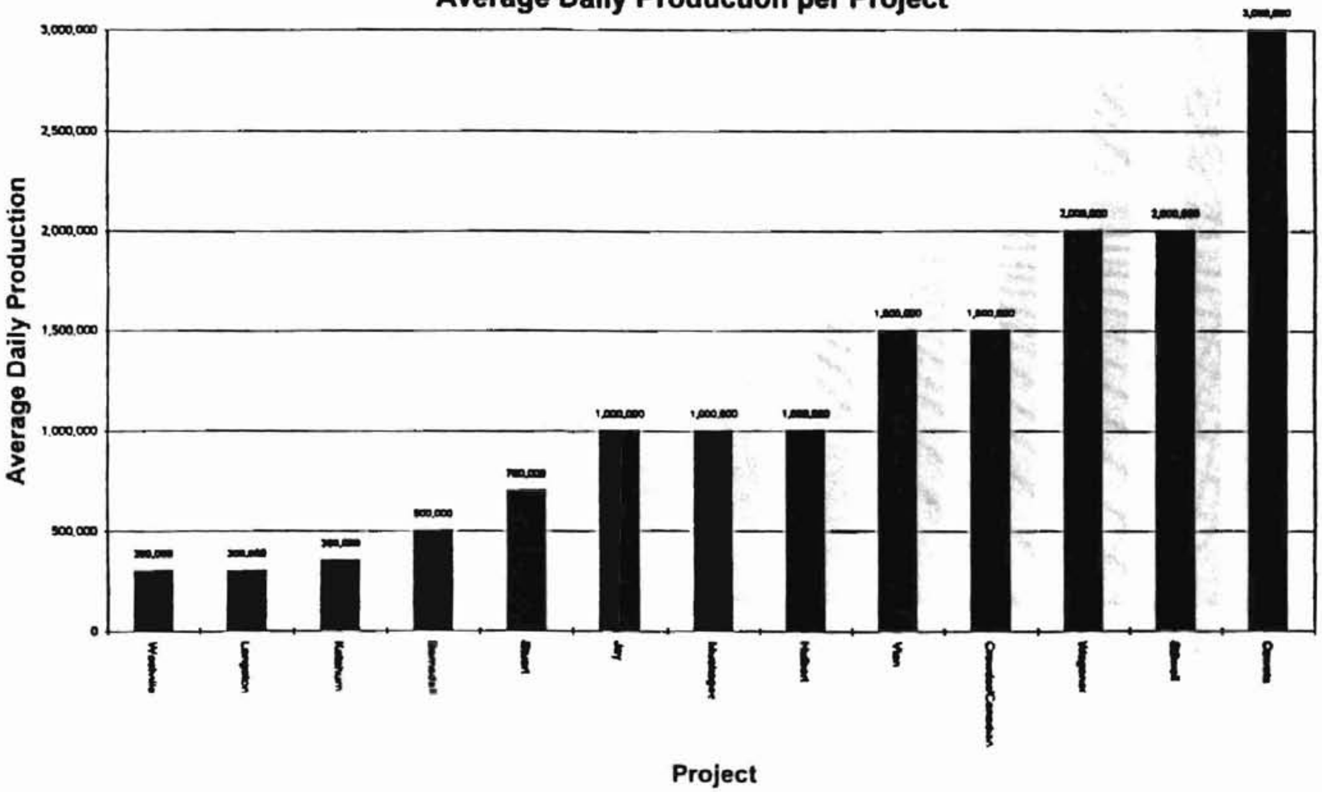
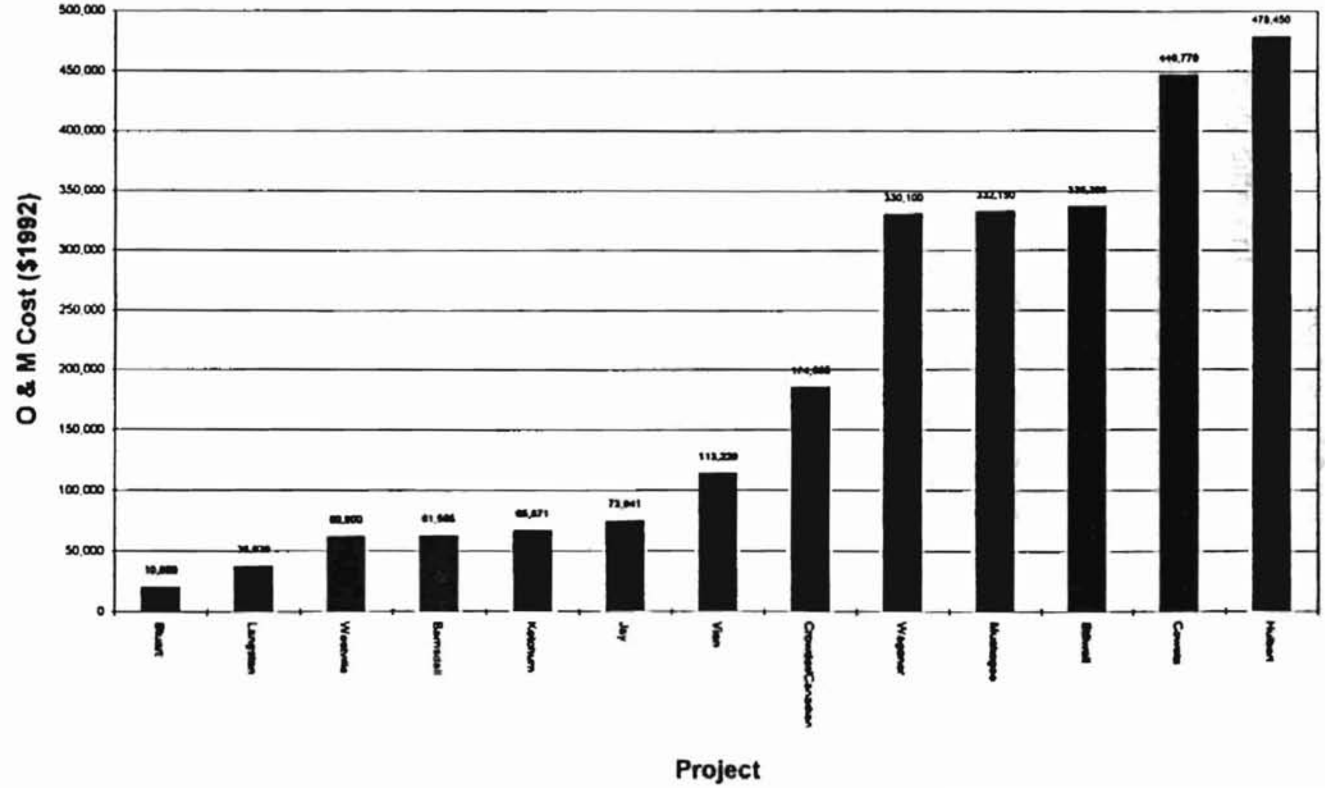


FIGURE 8

Operating and Maintenance Cost per Project



treatment can be defined as using a heavier filtration unit. This is observed in Table II where Wagoner and Coweta both use slow sand filtration, yet the difference may be attributed to the raw water source . Not only are O & M costs affected by the treatment type selected, but also the capital costs for each technology can be extremely different.

Capital costs on an annual basis are presented in Figure 9. Although, Hulbert had the highest O & M cost this is not the case when evaluating its annual capital cost of $207,015. This type of relationship is also present at the other end of the spectrum where an example would be the project at Westville. Westville had a low O & M cost as depicted in Figure 8 and the second highest annual capital expense as illustrated in Figure 9. Data in Figure 10 illustrates the total annual costs per project with Westville ranking 8th overall. Hulbert has the highest total annual cost at $685,465 followed by Coweta at $633,932. Annual total cost per project are capital dominant figures. The expense of building a new treatment plant, initially, is capital dominant. Because of large capital costs, many decisions about whether to build or not to build are also based upon capital expense. Often, not enough attention is given to O & M costs for the various types of treatment. In some cases, capital costs may be relatively low and O & M costs relatively high. The understanding of what effects total annual costs per treatment is crucial for good decision making when determining to build a water treatment facility. To understand the effects upon annual capital, O & M and total costs, the next section focuses upon an

FIGURE 9

Annual Capital Cost per Project

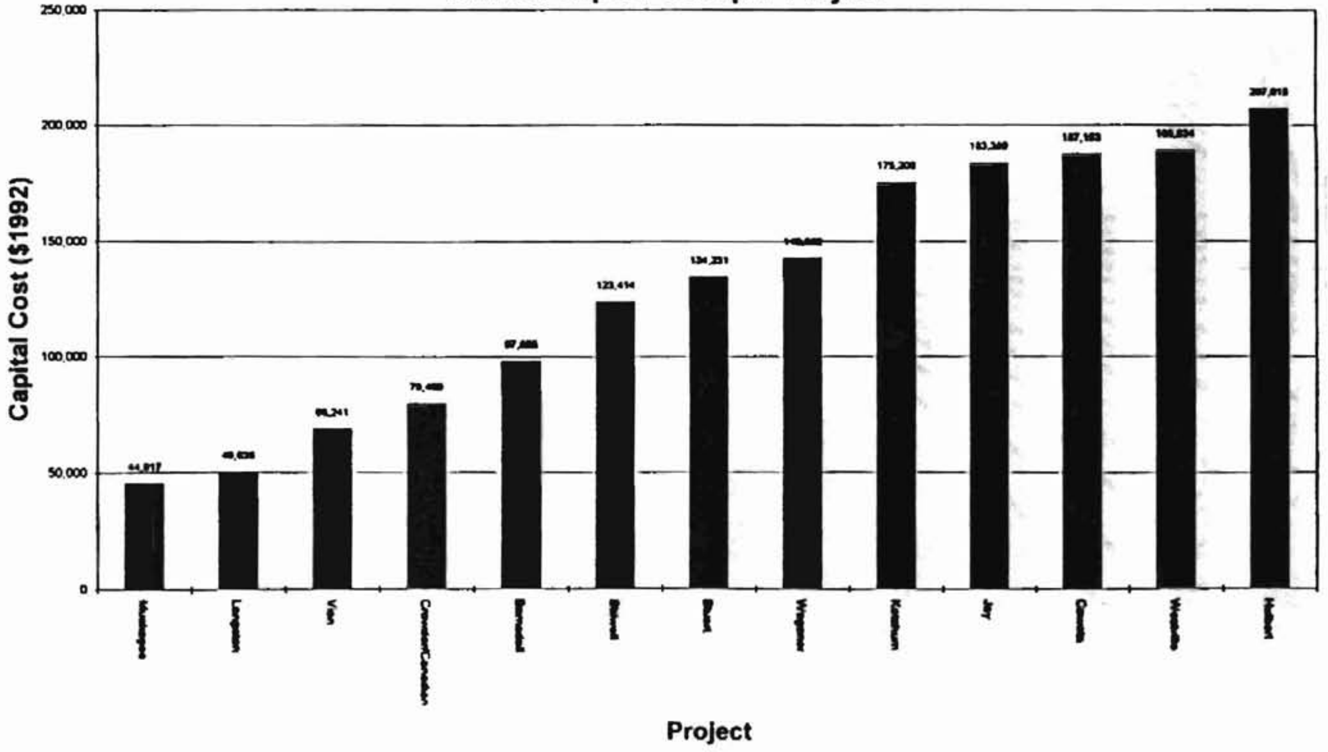
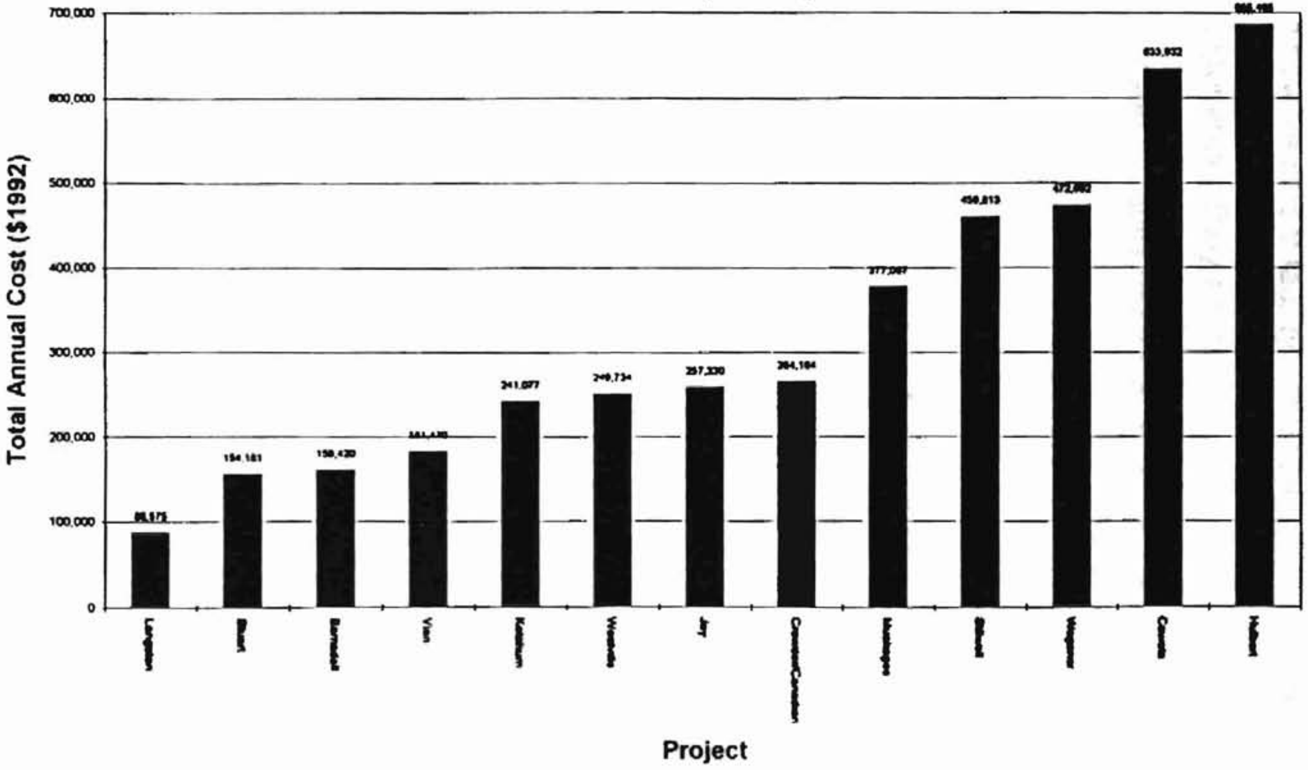


FIGURE 10

Annual Total Cost per Project



explanatory power or R-square analysis of the variables.

Explanatory Power

The explanatory power analysis focuses on annual capital, O & M and total costs of building a new treatment facility. The factors affecting these costs are divided into two components. They are population served and ADD. These two components were chosen because treatment systems are classified usually by output in terms of ADD or by the amount of people the system serves. Both component effects are observed upon the annual capital, O & M and total costs. The R-square values found in Figures 11 through 18 were selected based on the highest R-square value using several functional forms. R square is the value of explained variation in the dependent variable by the information contained within the independent variable and its value will always be between 0 and 1 (Greene, 1993). The functional forms included linear, polynomial, power and logarithm. These were evaluated for each figure and the highest R-square value was reported.

Annual Capital Cost

The effect of population served upon annual capital costs is depicted in Figure 11. The R-square value is .0699. Population served does not do a good job in explaining the variation found in annual capital costs. The type of treatment heavily dictates the capital costs and this is true also for O & M costs. The same type of effect is observed in Figure 12 when a R-square value of

FIGURE 11
Annual Capital Cost versus Population Served

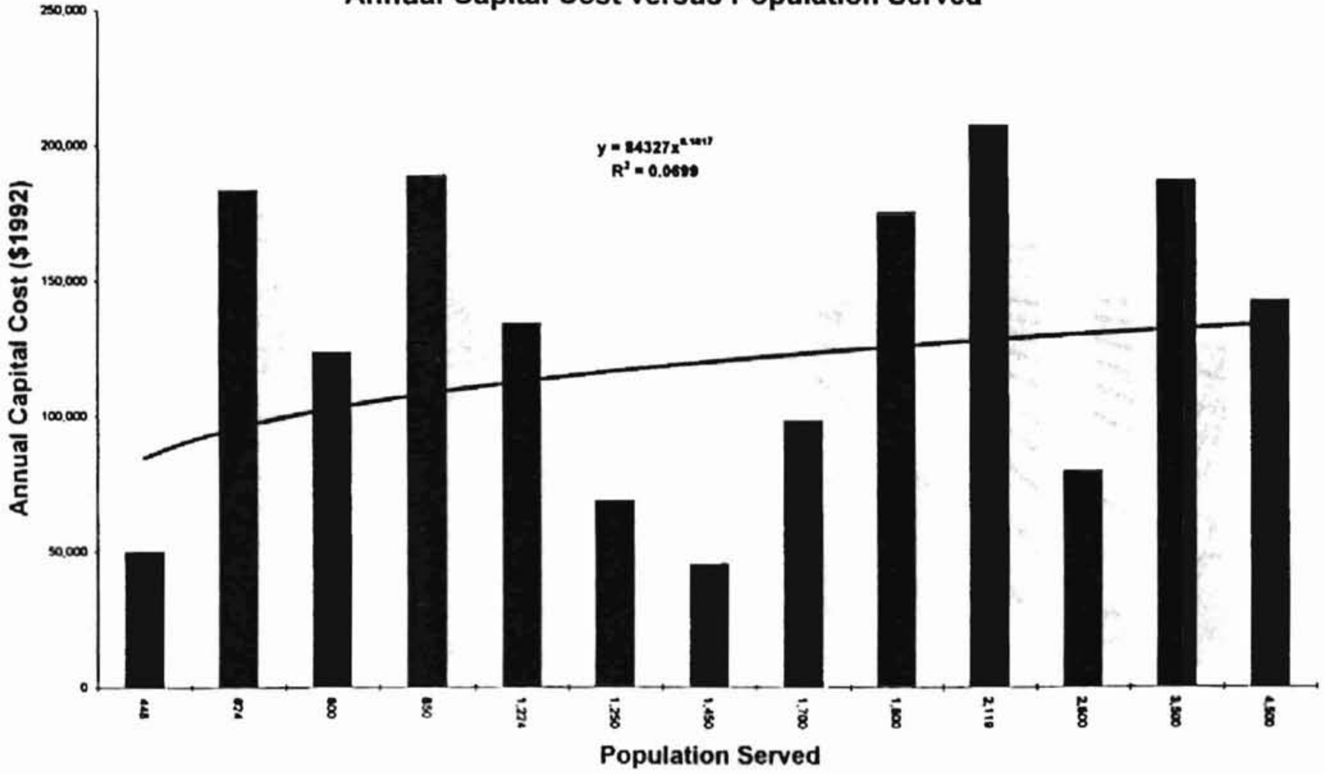
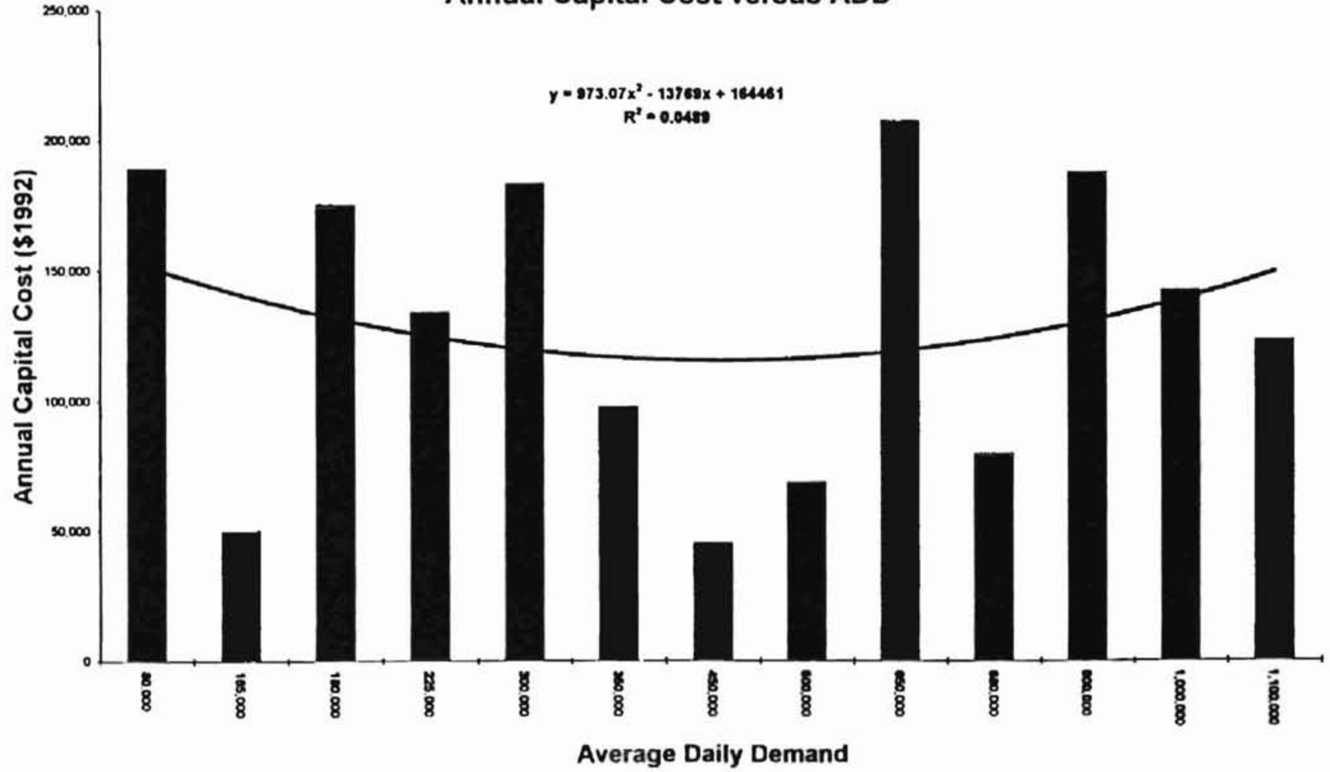


FIGURE 12
Annual Capital Cost versus ADD



.0489 is observed when measuring the effect ADD has upon annual capital costs. In this case, ADD does not do a very good job of explaining the variation. Again, the annual capital costs are primarily dictated by the type of treatment technology required to be used. At this point, only the effects of population and ADD have been observed upon annual capital and O & M costs. To observe these effects upon the total annual cost, additional R-square analysis is needed.

Annual Operating and Maintenance Cost

Figure 13 illustrates the effects of population served on O & M costs for all treatment types. The R-square value is only .3377. This means only 33.77% of the variation in O & M costs are explained by the independent variable (population). Population does not always determine the amount of O & M costs. The rest of the variation is made up of randomness, variation in the quality of water sources, and differences in treatment technologies.

The effect of ADD upon annual O & M costs is illustrated in Figure 14. The R-square value is .6713. This is significantly higher than .3317. In other words, ADD does a better job in explaining the variation in O & M costs than population served. If the effects of ADD and population served were both observed, then the R-square value would increase. However, these combined variable effects will not be observed at this point. For now the discussion focuses upon the individual effects of population and ADD.

FIGURE 13

Annual O&M Cost versus Population Served

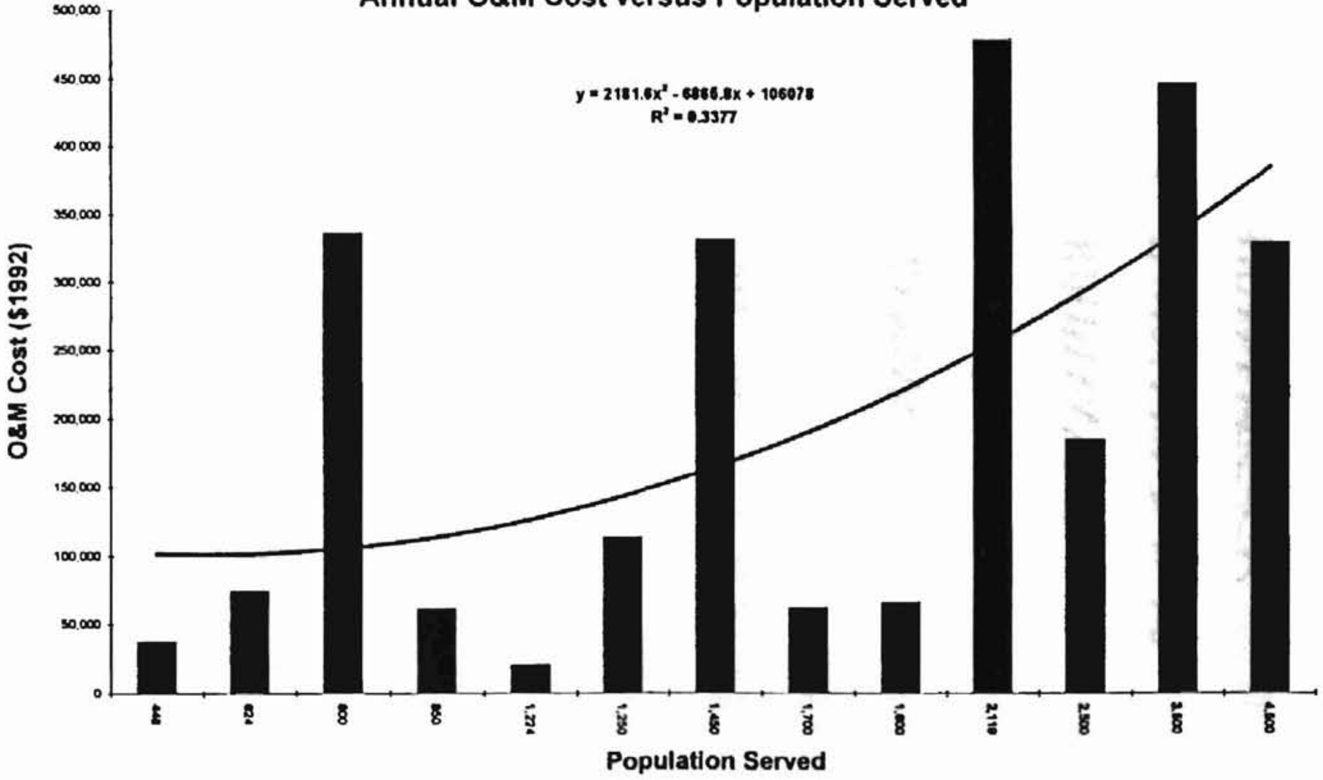
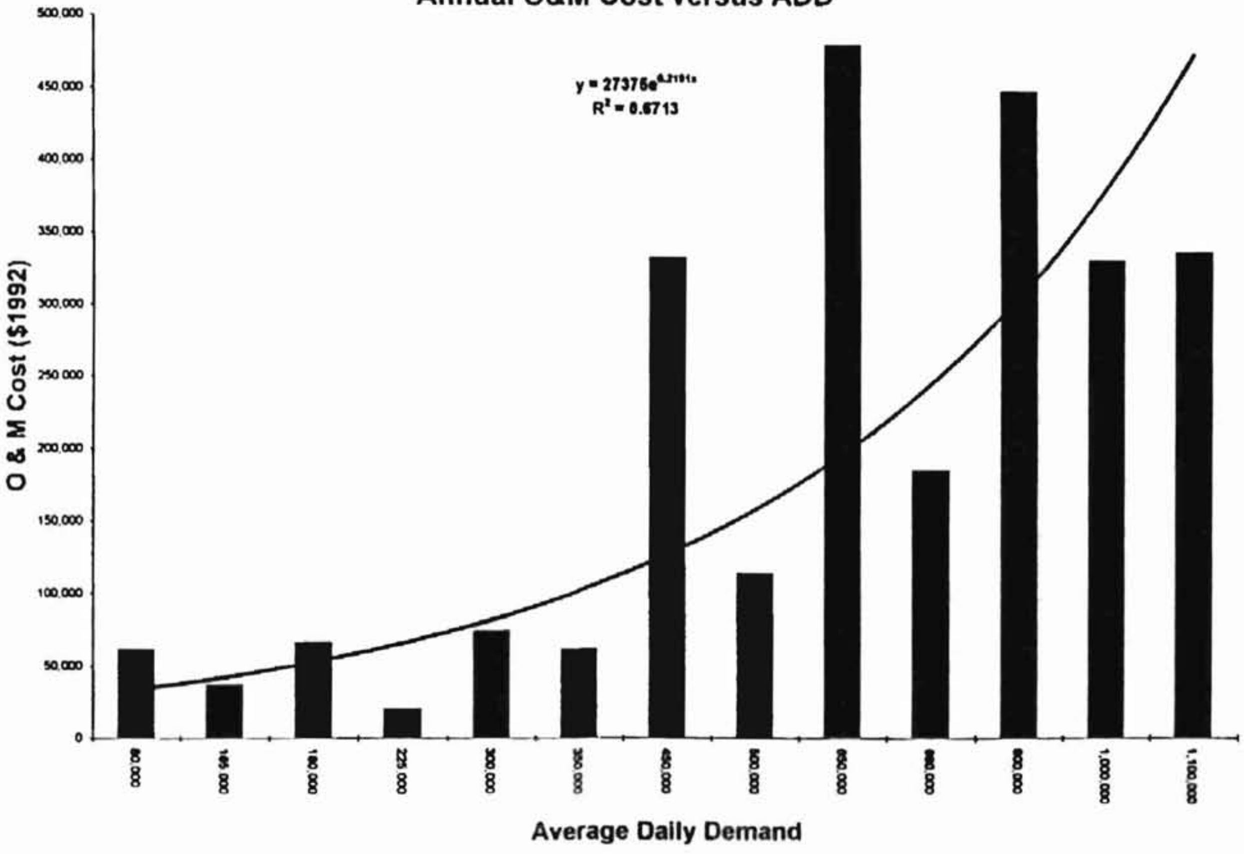


FIGURE 14

Annual O&M Cost versus ADD



Annual Total Cost

The effects of population served upon annual total cost is presented in Figure 15. The R-square value is .1179. Population served does not do a good job of explaining all the variation in annual total costs. Figure 16 depicts the effects of ADD upon total annual costs. The R-square value is .4899. ADD does a better job in explaining the variation in the total annual costs, but here again total annual costs are not solely dependent upon ADD nor population served.

The effects of population served on average total cost is illustrated in Figure 17. The R-square value is .2951. Population served, in this manner, does do a good job of explaining the variation in average annual total costs. Figure 18 shows the effects ADD has on average variable cost. The R-square value is .0953. ADD does a poor job in explaining the variation found in average variable cost.

The R-square classifications identified which variables explained the most variation in annual total costs of treatment. Understanding which variable explains the most amount of variation in annual total costs aids in also understanding the relationship between output and annual total costs. The relationship between annual total costs and output is of great concern for rural Oklahoma water systems. With increased regulations, rural Oklahoma water systems need to be more informed about how the costs of providing water may change given changes in the size of each respective system. Typically,

FIGURE 15
Annual Total Cost versus Population Served

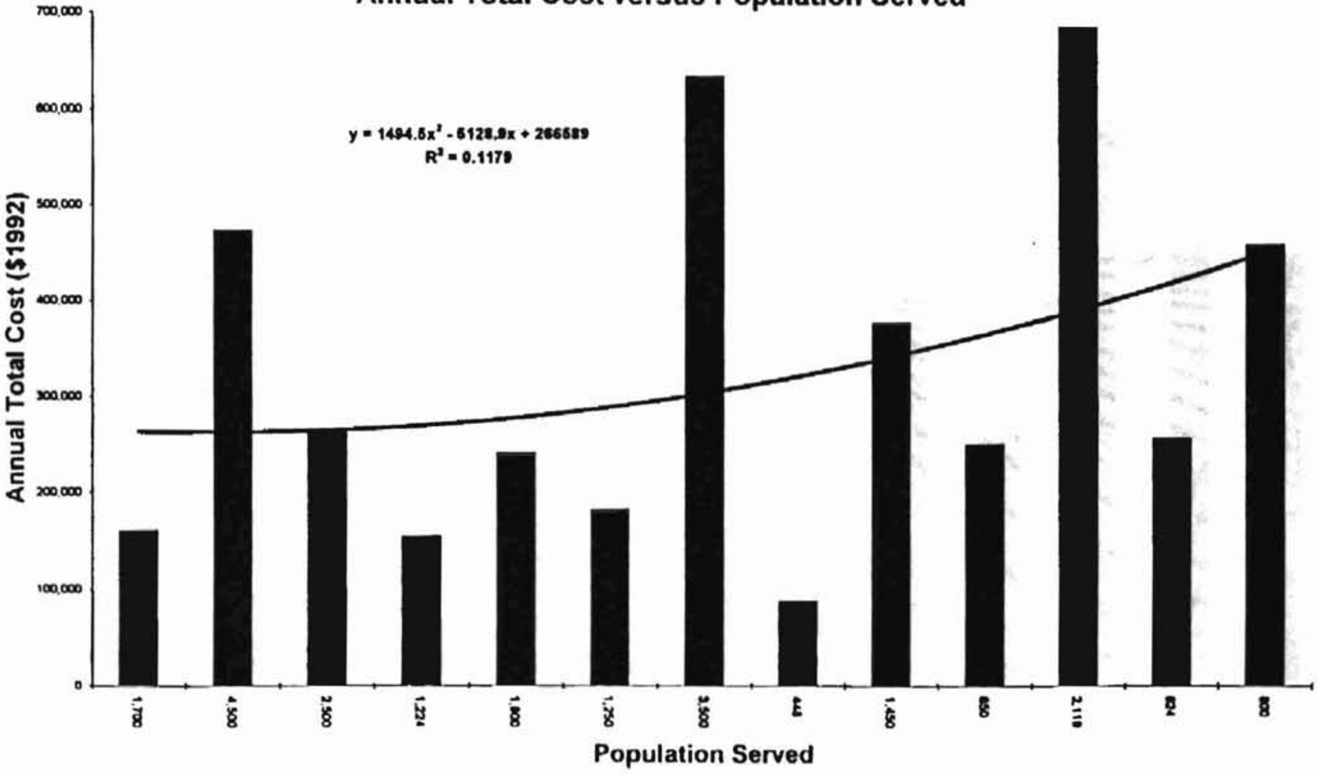


FIGURE 16

Annual Total Cost versus ADD

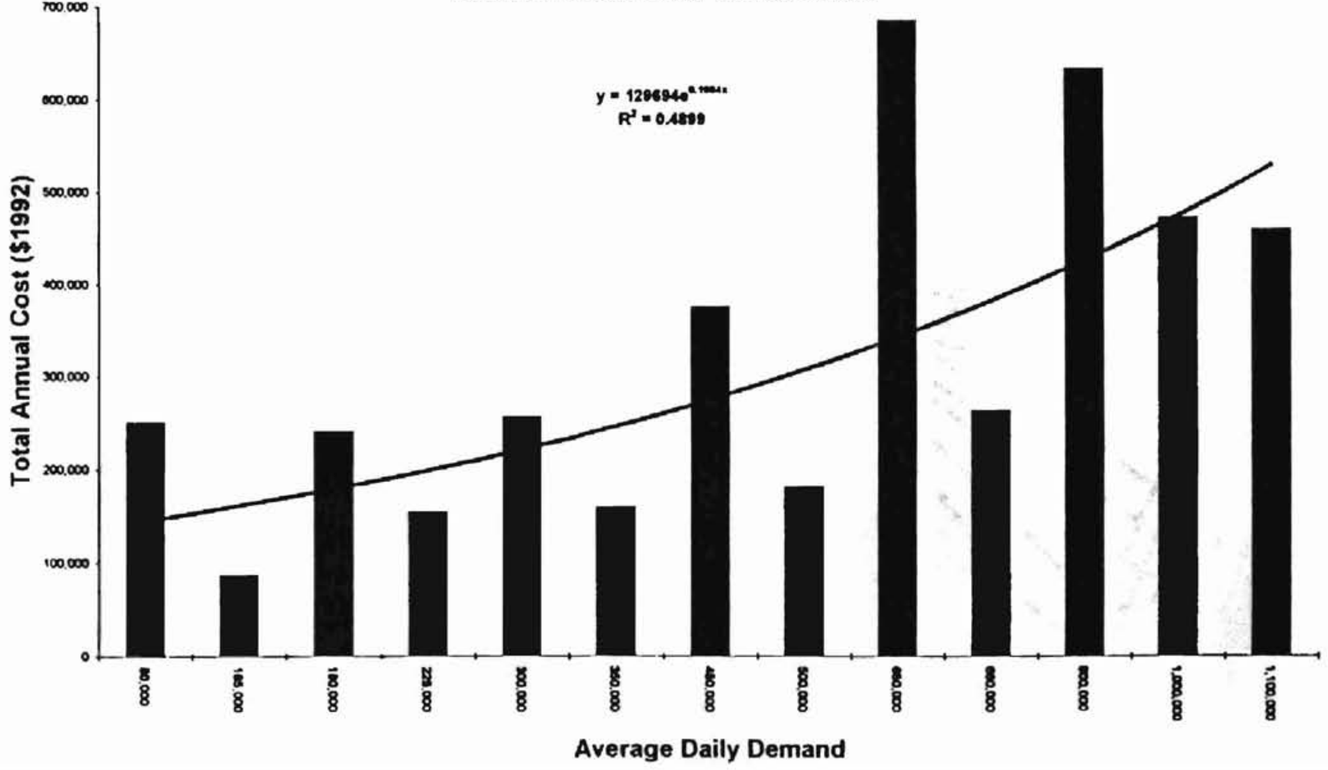


FIGURE 17

Average Total Cost versus Population Served

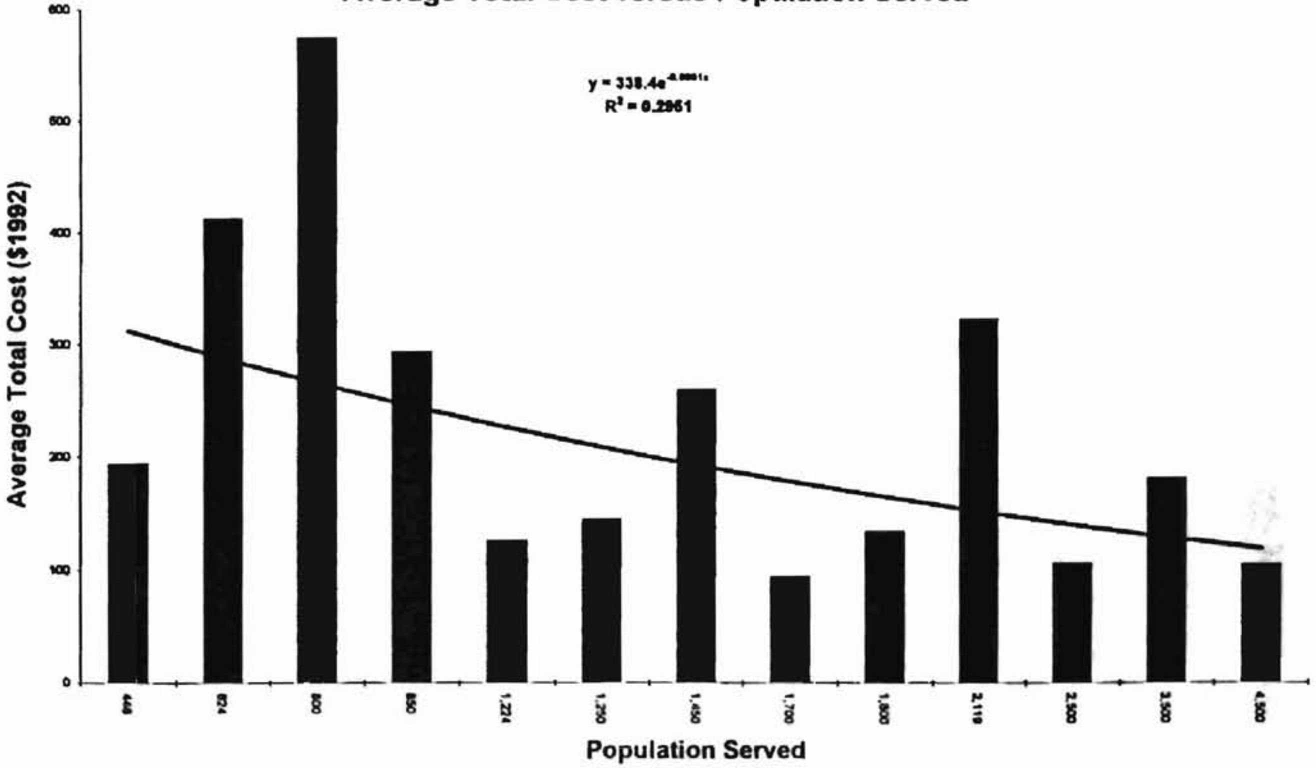
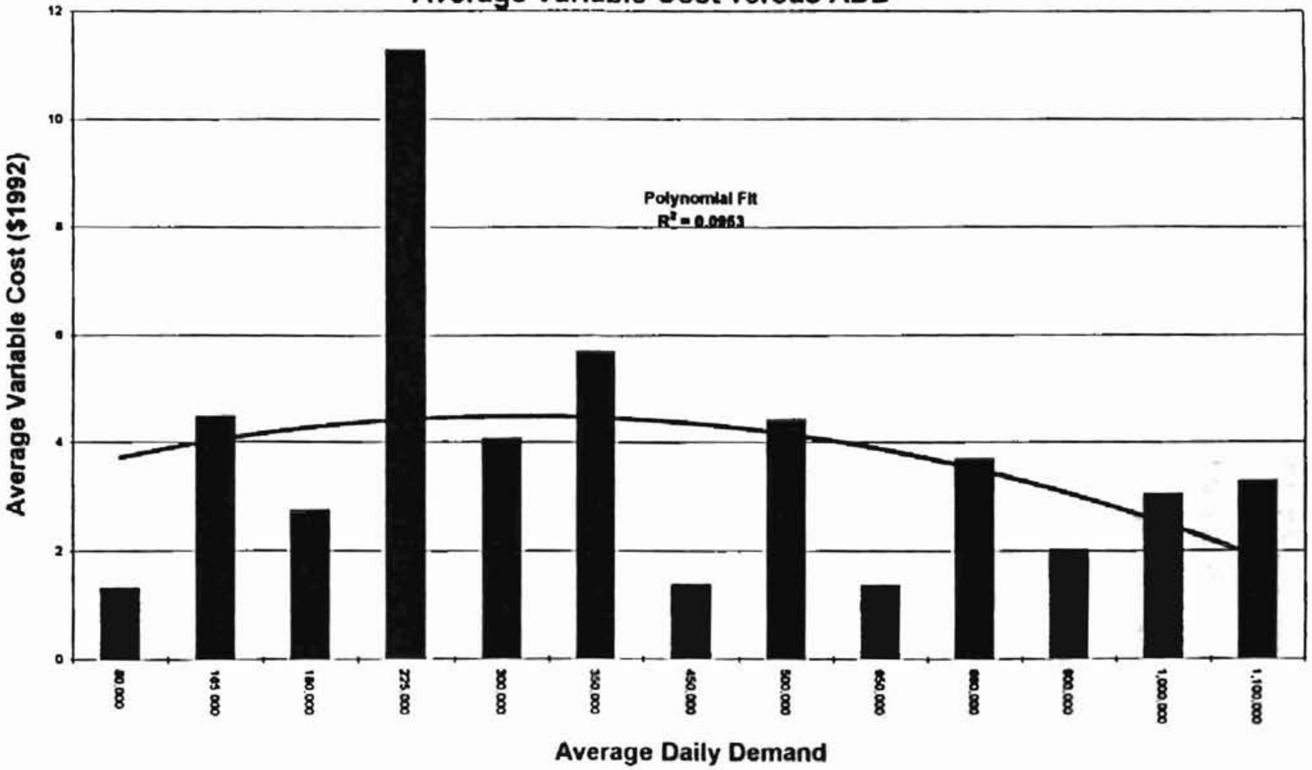


FIGURE 18
Average Variable Cost versus ADD



rural systems serve a very small amount of people and as a result the average cost per unit is higher than compared to a large decentralized system. This occurs because the larger system can spread additional costs such as increased monitoring costs over more people. The rural systems are not able to spread the additional costs over more people because of a limited number of users. As the cost of compliance increases for all systems, clearly, rural systems face the greatest challenge in meeting compliance. The economic condition known as economies of size has to do with the economic condition of what is happening (decreasing, constant, or increasing) to costs as output is expanded (Beattie and Taylor 1993). To determine if the systems in this data set are experiencing this economic condition, a theoretical and empirical framework is needed. The theoretical and empirical frameworks are defined and explained in Chapter IV.

CHAPTER IV

PROCEDURES

This chapter discusses the assumptions made in estimating annual capital, operating and maintenance (O & M) and total costs. The discussion also focuses upon the statistical tests conducted to determine which variable should be used for output. This is achieved by the use of a Wald test. Finally, each empirical model used in testing the economies of size hypothesis is explained.

Assumptions

Annual Capital Costs

The annual capital cost values represent the total capital investment per project annualized using an interest rate of 8% over a 20 year life. The differences in total cost can be attributed to capital cost more than O & M cost because the treatment equipment often requires a large initial investment.

Annual Operating and Maintenance Costs

To simulate annual O & M cost estimates, many assumptions within each observation had to be made. There were two components that made up annual O & M costs. They are treatment costs and additional costs. The treatment costs were estimated using the equations from the BAT document. Additional costs included costs for land, buildings, fencing, roads, wellhead pumps and the replacement of any distribution systems. To estimate the actual O & M costs for each treatment technology, each observation's cost were adjusted for changes found in the additional cost components. Specific characteristics of each project's additional cost adjustments can be found in Appendix B. If an observation had land available to build the facility on, then no additional land cost would be included for the observation. If however, the observation had to purchase land, then the model was adjusted for this type of purchase and the same type of adjustment occurred for each component of additional cost for each observation. The adjustment of each observation attempts to ensure the consistency and accuracy of each cost estimate.

Annual Total Cost

The total annual cost of treatment for each project is derived by summing the annual capital costs and the annual O & M estimates. This yields total annual costs per treatment for each project. Each total annual cost value is reported in 1992 dollars.

Wald Statistical Tests

To determine which variable should be used for output, Wald statistical tests were conducted. The variables observed and tested were population served, average daily demand (ADD) and average daily production (ADP). The Cobb Douglas form of the model for this testing is:

$$(16)\quad \ln TC = A + \beta_1 \ln POP + \beta_2 \ln ADD + \beta_3 \ln ADP + e$$

where, TC = Total Annualized Cost,
POP = Population served,
ADD = Average Daily Demand,
ADP = Average Daily Production,
A = Intercept, and
e = Error or Disturbance term.

The null and the alternative hypotheses are:

$$\begin{aligned}&\text{Ho: } \beta_i = 0,\ \beta_i = 0 \quad i(1\&2,\ 2\&3,\ 1\&3)\\ &\text{Ha: } \beta_i \neq 0,\ \beta_i \neq 0\,.\end{aligned}$$

Each variable was tested by setting the other variables equal to zero. This is a form of restricted least squares. The null hypothesis states that two of the variables are not significantly different from zero in the model and the alternative states they are significantly different. To test if POP is significantly different from zero within the model, ADD and ADP are set equal to zero and the significance of the F-statistic for the model is observed. The same procedure is conducted to test for the other variables. The restricted tests were conducted upon the Translog form as well. The model used to test the Translog functional form is:

$$(17)\ \ln TC = A + \beta_1 \ln POP + \beta_2 \ln POPSQ + \beta_3 \ln ADD + \beta_4 \ln ADDSQ + \beta_5 \ln ADP + \beta_6 \ln ADP + e$$

where,
TC = Total Annualized Cost,
POP = Population served,
POPSQ = Population served squared,
ADD = Average Daily Demand,
ADDSQ = Average Daily Demand squared,
ADP = Average Daily Production,
ADPSQ = Average Daily Production squared,
A = Intercept, and
e = Error or Disturbance term.

The null and the alternative hypotheses are:

$$\begin{aligned}&\text{Ho: } \beta_i = 0,\ \beta_i = 0,\ \beta_i = 0,\ \beta_i = 0 \quad i(3,4,5,\ 6 \text{ or } 1,2,5,6 \text{ or } 1,2,3,4)\\ &\text{Ha: } \beta_i \neq 0,\ \beta_i \neq 0,\ \beta_i \neq 0,\ \beta_i \neq 0\end{aligned}$$

The same test was conducted to determine which variable was the best to use for output for the Translog function. To test this condition, all other variables were set equal to zero except one and the significance of the F- statistic was observed at the 5% level of alpha. In other words, to test for POP, all other variables are set equal to zero except for β_1 and β_2. This is a form of restricted least squares because the model is restricted by the equal to zero conditions.

Empirical Models

There are eight empirical models defined below. These models are estimates of an indirect cost function assuming the Cobb-Douglas (CD) and Translog functional forms. The indirect cost function is a function of input prices and output. In this analysis, the input prices are fixed. This causes the indirect cost function to be a function of output. Output can be defined many ways such as population served or the amount of water each facility can treat for distribution and consumption. Even though the Wald tests are designed to determine which output variable is the best, all other output variables are reported. Based upon Chapter III, ADD, ADP and population served all explain some of the variation within total annualized costs. For this reason, all models using different definitions of output, and functional forms will be evaluated and tested. Each empirical model is in natural logarithmic form. These types of models are often referred to as double log models or log log models.

Model 1 (A, B, C)

Model 1A refers to the aggregate Cobb-Douglas functional form where output is defined as population served for each project. Using Ordinary Least

Squares (OLS) estimation procedures, the log of total annualized cost is regressed against the log of population served. Empirical Model 1A is:

$$(18)\ \ln TC = A + \alpha \ln POP + e;$$

where A is the intercept and α is the estimated parameter and e is the error term. If the coefficient on lnPOP is significant from one (alpha = .05 and .10), then economies of size exists. The same type of coefficient test will be performed for all models. The magnitude of economies of size is determined by α, which is the function coefficient. Model 1 also defines output as ADD and ADP. These two other definitions of output are referred to as Model 1B and Model 1C, respectively. Model 1B and 1C are derived the same as Model 1A. The difference is the log of total annualized cost is now regressed against the log of ADD, and ADP. The same statistical tests and implications of economies of size apply to Model 1B and Model 1C.

Model 2 (A, B, C)

Model 2A defines output as the population served per project. Model 2B defines output as ADD and Model 2C defines output as ADP. Models 2A, 2B, and 2C assume the CD functional form. OLS estimation procedures will be used to regress the log of total annualized cost against each of the defined variables for output . Empirical Model 2A is:

$$(19)\ \ln TC = A + \alpha \ln POP + \delta D1 + e;$$

where A is the intercept, α is the estimated parameter, δ is the estimated parameter for the use of a dummy variable (D1) and e is the error term.

Observations using slow sand technology receive a 1 and 0 otherwise. The use of D1 is employed to test if slow sand technology was significantly different from zero. The function coefficient, α, retains all economies of size implications even though the use of D1 is employed. If the coefficient, α, is significant from 1 at alpha equal to 5% or 10%, then economies of size do exist. The same type of significance test applies to Model 2B and Model 2C.

Model 3 (A, B, C)

Model 3A, 3B and 3C assume the Translog functional form. Output in Model 3A is defined as population served. OLS is used for estimation procedures where the log of total annualized costs are regressed against the log of POP, and POPSQ. Model 3B and 3C defined output as ADD and ADP, respectively. The OLS procedures for Model 3B and 3C are the same as Model 3A, except β_1 and β_2 would represent estimated coefficients for ADD, ADDSQ for Model 3B and ADP, and ADPSQ for Model 3C. Empirical Model 3A is:

$$(20)\ \ln TC = A + \beta_1 \ln POP + \beta_2 \ln POPSQ + e$$

where,
TC = Total Annualized Cost,
POP = Population served,
POPSQ = Population served squared,
A = Intercept, and
e = Error or Disturbance term.

To determine if economies of size exist, two different methods may be employed. A significant t-test upon the coefficient for POP, ADD, ADP would conclude economies of size do exist or if $1 - \partial \ln TC / \partial$ output (POP, ADD, ADP) is positive. A negative value would conclude diseconomies of size.

Model 4 (A, B, C)

Models 4A, 4B and 4C are identical to Models 3A, 3B and 3C except for the addition of D1. Empirical Model 4A is:

(21) $lnTC = A + \beta_1 ln\ POP + \beta_2 ln\ POPSQ + \delta D1 + e$

where, TC = Total Annualized Cost,
POP = Population served,
POPSQ = Population served squared,
D1 = Dummy variable (1 if slow sand technology, 0 otherwise)
A = Intercept, and
e = Error or Disturbance term.

Models 4B and 4C assume the same Translog form defining output as ADD and ADP. It is hypothesized slow sand technology is significantly different from the other technologies because of the cost structure associated with each technology. For this reason, D1 is used to determine if slow sand is significantly different from the other technologies. A significant (alpha = 5% or 10%) t-test upon D1 would conclude slow sand technology is significantly different from other technologies. The same economies of size tests apply to Models 4A, 4B, and 4C as did for Models 3A, 3B and 3C.

Model 5 (A, B, C)

Models 5A, 5B, and 5C assume the CD functional form. These models represent treatment technology regressions. The log of total annualized costs is regressed against the log of output (POP, ADD, ADP). Empirical Model 5A is:

(22) $lnTC = A + \alpha\ lnPOP + e;$

where A is the intercept and α is the estimated parameter and e is the error term. If the coefficient on ln output (POP, ADD, ADP) is significant from one (alpha = 5% or 10%), then economies of size exists. Models 5A, 5B, and 5C are identical to Models 1A, 1B, and 1C. The difference is the type of observations. Models 1A, 1B and 1C represented the aggregate CD where the sample size was equal to 13. In other words, the CD aggregate models used all of the treatment technologies together to estimate an aggregate indirect cost function. In Models 5A, 5B and 5C, the sample size is reduced to 7 because only observations using slow sand technology are used to estimate an indirect cost function for slow sand technology.

Model 6 (A, B, C)

Models 6A, 6B, and 6C assume the CD functional form. These models represent package plant treatment technologies. The sample size reduces to 4 observations for this treatment technology. Empirical Model 6A is:

(23) $lnTC = A + \alpha \, lnPOP + e;$

where A is the intercept and α is the estimated parameter and e is the error term. If the coefficient on ln output (POP, ADD, ADP) is significant from one (alpha = 5% or 10%), then economies of size exists.

Model 7 (A, B, C)

Models 7A, 7B, and 7C assume the Translog functional form and represent regressions for slow sand technology. The sample size is 7.

Empirical Model 7A is:

(24) $lnTC = A + \beta_1 ln\ POP + \beta_2 ln\ POPSQ + e$

where, TC = Total Annualized Cost,
POP = Population served,
POPSQ = Population served squared,
A = Intercept, and
e = Error or Disturbance term.

Economies of size exist if a significant t-test upon the coefficient for POP, ADD, ADP is found or if $1- \partial \ln TC/\partial$ output (POP, ADD, ADP) is positive. A negative value would conclude diseconomies of size. Models 7B and 7C defined output as ADD and ADP, respectively.

Model 8 (A, B, C)

Models 8A, 8B, and 8C assume the Translog functional form and represent regressions for observations using package plant technology. The sample size is 4. Empirical Model 8A is:

$$(25)\ \ln TC = A + \beta_1 \ln POP + \beta_2 \ln POPSQ + e$$

where, TC = Total Annualized Cost,
POP = Population served,
POPSQ = Population served squared,
A = Intercept, and
e = Error or Disturbance term.

Economies of size exist if a significant t-test upon the coefficient for POP, ADD, ADP is found or if $1- \partial \ln TC/\partial$ output (POP, ADD, ADP) is positive. A negative value would conclude diseconomies of size. Models 8B and 8C defined output as ADD and ADP, respectively.

Concerns

Because the data are cross-sectional, certain estimation problems could arise. These include problems of heteroscedasticity and non-normality of the error terms. If encountered, these problems will be corrected by using a better estimator or identifying a potential outlier within the data set. In either case, the estimation procedures chosen to handle these problems will be unbiased and the most efficient (minimum variance). All models will be estimated without any type of dummy variable (D1) implementation. If however, there is a problem with non-normality or if an outlier is found within the data set, then D1 will be used as an intercept shift for that observation. Other than estimation problems, D1 will be used to separate the effects of the various treatment technologies. Specifically, D1 is used to test if slow sand technology is significantly different from other technologies for both functional forms of the indirect cost functions. This test is conducted because a large portion of observations use slow sand technology (7 out of 13). Observations that use slow sand technology would receive a 1 and 0 otherwise. The mean of the dummy variable represents the proportion of observations using slow sand treatment technology.

CHAPTER V

EMPIRICAL RESULTS AND DISCUSSION

The empirical results and discussion focus upon six areas. They are (1) estimation corrections, (2) Wald test results, (3) aggregate Cobb-Douglas (CD) total cost estimation results, (4) aggregate Translog total cost estimation results, and (5) treatment technology estimations. The estimation corrections section discusses any problems in estimating the indirect cost functions for all models and reports any changes in estimation procedures. The Wald statistical tests were conducted to determine which variable should be used for output. The aggregate models used all 13 observations to estimate aggregate total cost equations (with and without the use of a dummy variable) using all technologies for both the CD and Translog functional forms. Total cost equations were estimated by treatment type for both functional forms as well.

Estimation Corrections

Ordinary Least Squares (OLS) was used for all models. No heteroscedasticity or non-normality of error terms were observed in any of the models. Because these problems did not exist, there were no estimation corrections made. OLS estimation procedures were unbiased and most efficient.

Wald Test Results

The Wald tests for the CD and Translog models did not find one output variable to be significantly better than the other at alpha equal to 5% or 10%.

For this reason, all estimated models for both functional forms used population served, ADD, and ADP as output.

Aggregate Cobb-Douglas Results

The aggregate CD models using all output variables without the use of D1 are reported in Table IV. Most of the discussion will center around the CD models with population served as the output measure as this output measure has more policy implications. The other models are discussed. All of the output models are significant at alpha equal to 5%. Table V illustrates the effects of D1 upon each of the three output models. Because the D1 coefficient was insignificant at alpha equal to 5% or 10%, the output models discussed below are derived from Table IV. Each output model is discussed and total, average, and marginal cost curves are illustrated.

In Table IV, the aggregate CD model using the POP variable for output was significant at the 5% level and the coefficient on the POP variable was significant at the 5% level as well. The POP coefficient is positive and because it was statistically significant at the 5% level, the null hypothesis of diseconomies of size was rejected in favor of the alternative hypothesis of economies of size. The sign on the coefficient POP is correct. The sign is positive, which indicates as the population served for each system rises, so does annual total cost of providing the water. The (b+c) value represents the function coefficient which is the estimated parameter of .53808. Because .53808 < 1, this function exhibits decreasing returns to size. In isoquant space, this means as output is increased the isoquants get farther apart everywhere on the surface (Beattie and Taylor, 1993). In other words, cost rises less proportional as output is increased. Since (b+c) < 1, then average cost is decreasing. Marginal cost lies below average cost. The CD model, using population served as the independent variable, explained 35.51% of the variation within the dependent variable of total annual cost (Table IV). The implied economies of size is 1.86. Proof of total cost (TC) rising less proportional as output is increased can be observed in Figure 19. Also, proof of average cost (AC) being above marginal cost (MC) is illustrated in Figure 20. At a population served range between 200 and 1,000, AC (on an annual basis) is significantly higher compared to a range between 1,000 and 4,400. The smaller systems experience a higher AC for treatment because of their inability to spread the additional costs over a larger population served. The larger systems are able to spread the additional costs over a larger population, therefore the larger systems are more likely to experience economies of size. The aggregate CD model using ADD was significant at alpha equal to 5%. The sign on the coefficient of ADD is positive and correct. Total annual costs rise as ADD is increased. The R-square value is .4340. The ADD output model does a better job of explaining the variation in total annual costs than the POP model. The implied economies of size is equal to 2.00. Because (b+c) < 1, this function exhibits decreasing returns to size. Costs rise less proportional as output is increased. This is illustrated in Figure 21. AC is decreasing and is above MC

TABLE IV

Regressions for Aggregate Cobb-Douglas without Dummy Variable

	POP	Std. Error	ADD	Std. Error	ADP	Std. Error
Constant	*8.6208	1.60	*6.0912	2.23	*5.2649	2.43
Coefficient	*.53808	.218	*.49985	.1728	*.52955	.177
R Square	.3551		.4320		.4496	
N	13		13		13	
Implied Economies of Size	1.86[a]		2.00[a]		1.88[a]	
Model Significance	*Yes		*Yes		*Yes	

*Indicates significance at the 5% level. **Indicates significance at the 10% level.

[a] is calculated for the Cobb-Douglas as 1/(b+c), (Beattie and Taylor, 1993).

Dependent Variable is Logarithm of Total Annual Cost . Independent variables are in Logarithmic form.

TABLE V

Regressions for Aggregate Cobb-Douglas with Dummy Variable

	POP	Std. Error	ADD	Std. Error	ADP	Std. Error
Constant	*8.3458	1.66	*5.5021	2.31	*5.1962	2.05
Coefficient	*.59358	.233	*.55718	.182	*.53882	.190
D1	-.23831	.299	-.27782	.278	-.10878	.272
R Square	.3934		.4835		.4582	
N	13		13		13	
Implied Economies of Size	1.68[a]		1.79[a]		1.86	
Model Significance	*Yes		*Yes		*Yes	

*Indicates significance at the 5% level. **Indicates significance at the 10% level.

[a] is calculated for the Cobb-Douglas as 1/(b+c), (Beattie and Taylor, 1993).

Dependent Variable is Logarithm of Total Annual Cost . Independent variables are in Logarithmic form.

FIGURE 19

Aggregate Cobb-Douglas Population Served Total Cost

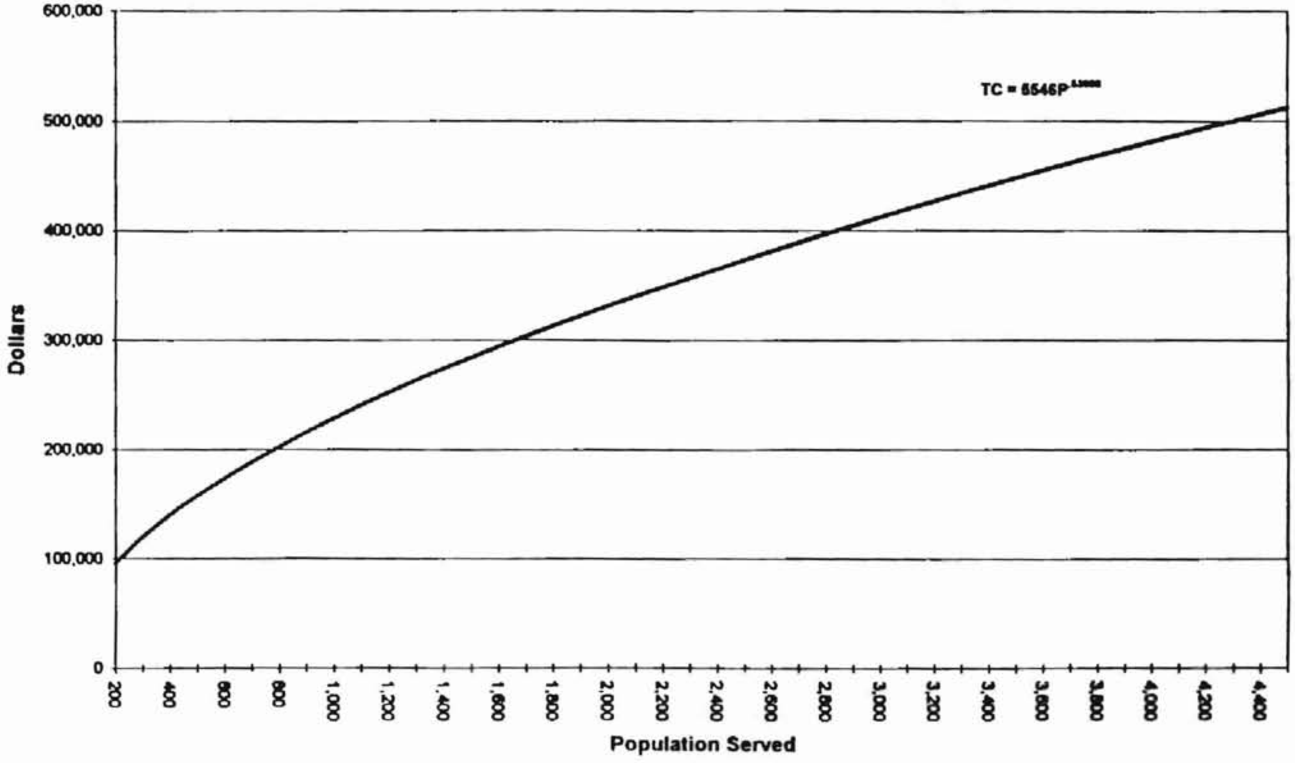
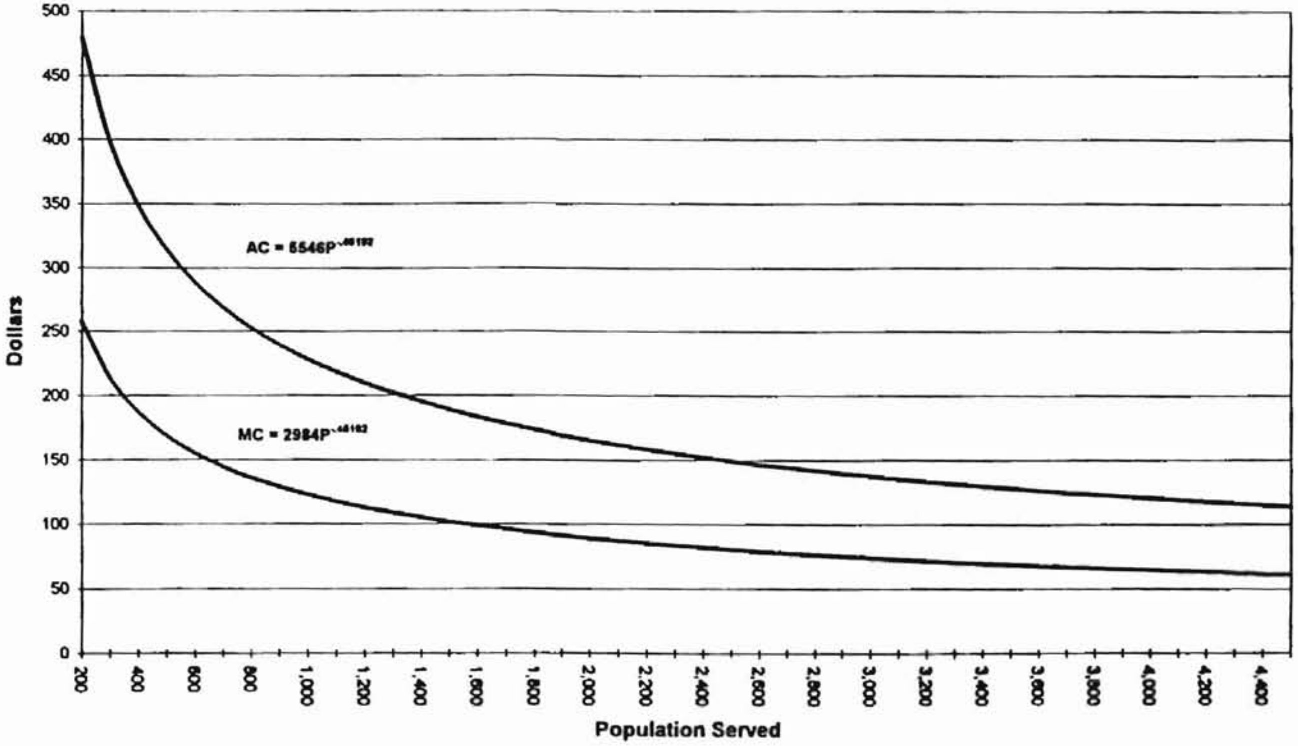


FIGURE 20

Aggregate Cobb-Douglas Population Served Average and Marginal Cost



everywhere. This is illustrated in Figure 22. The range of water in gallons measured by ADD is from 25,000 to 1,075,000 in Figure 22. The range between 25,000 and 200,000 experience a significantly higher AC than the range between 200,000 and 1,075,000. The inability to spread additional costs over a larger volume of water inhibits the smaller systems from reaching economies of size. The larger range is able to reach economies of size because of their ability to spread costs over more gallons of water.

The aggregate CD model using ADP as the output variable is significant at alpha equal to 5%. The sign on the coefficient ADP is positive and correct. Total annualized costs rise as ADP increases. The ADP model does the best job of the three in explaining the variation found in total annualized costs with a R-square value of .4496. The implied economies of size is 1.88. The (b+c) value or the estimated parameter is less than one. Because $(b+c) < 1$, this function exhibits decreasing returns to size. The aggregate CD ADP model reflects the same hypothesis decision as the other two output models and its proof of AC decreasing and being above MC everywhere is illustrated in Figure 23. All three aggregate CD models arrive at the same decision that economies of size exist. All three output models can be used to demonstrate how annual costs of treatment are impacted by changes in output.

FIGURE 21
Aggregate Cobb-Douglas ADD Total Cost

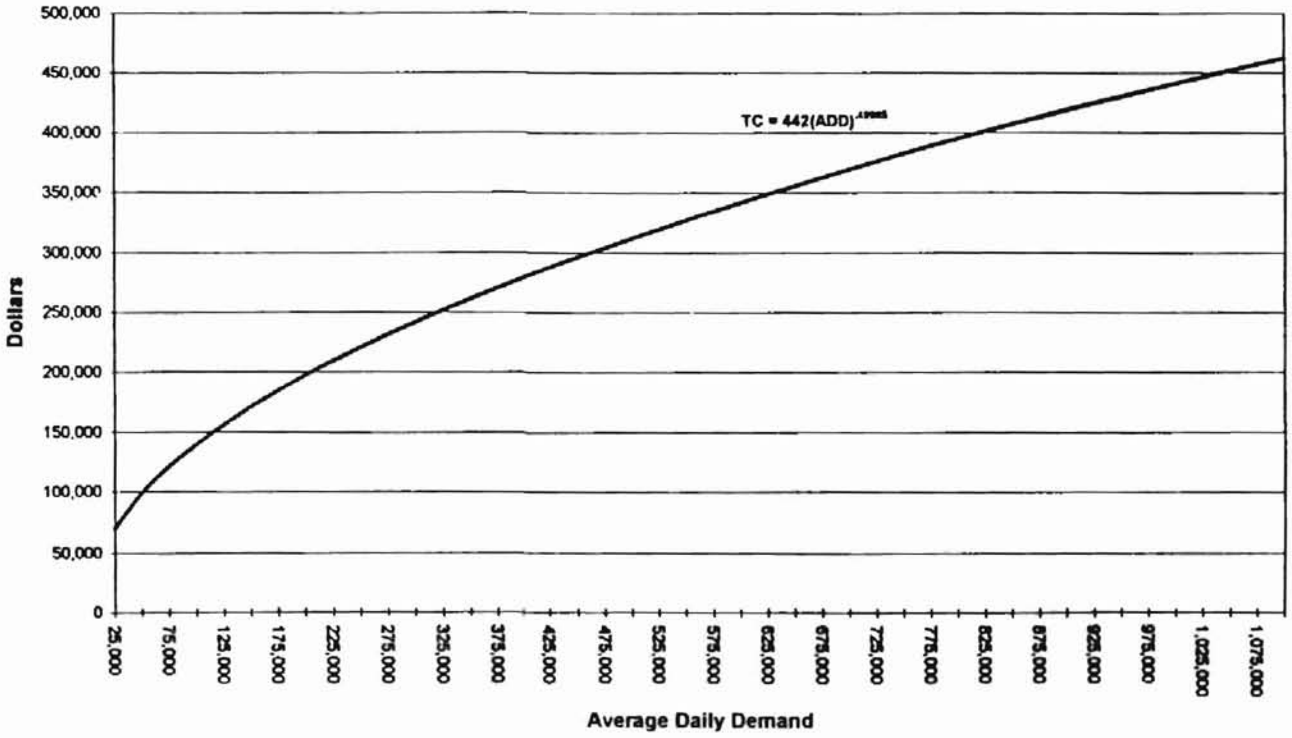


FIGURE 22

Aggregate Cobb-Douglas ADD Average and Marginal Cost

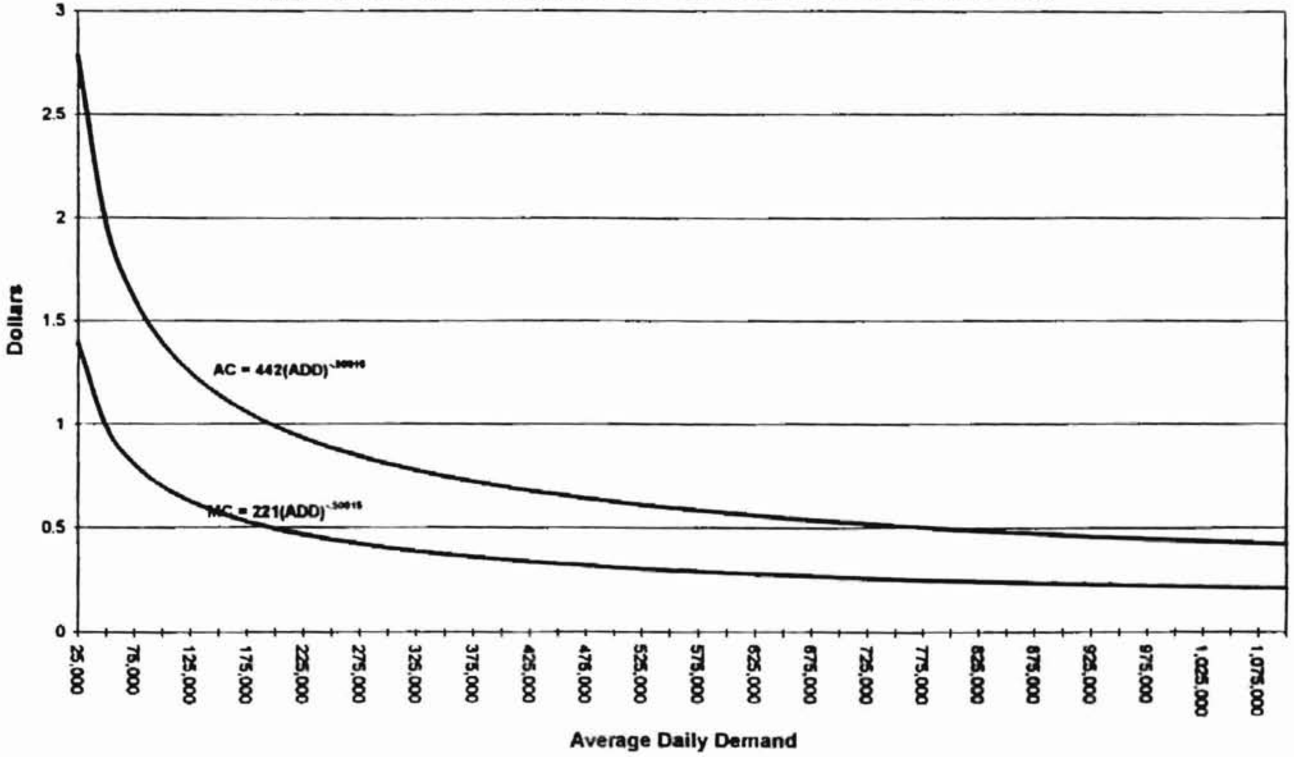
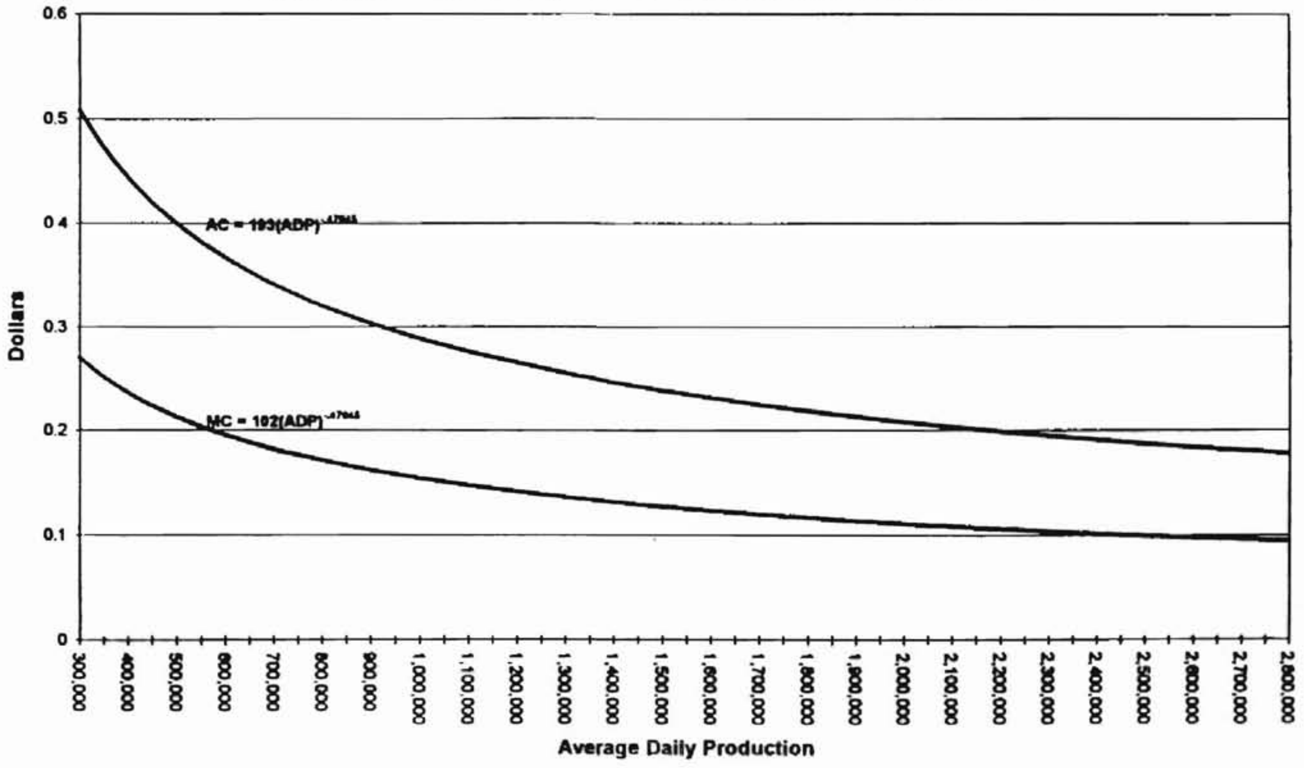


FIGURE 23

Aggregate Cobb-Douglas ADP Average and Marginal Cost



Aggregate Translog Results

The results of the three Translog models are presented in Table VI. The Translog POP model was found to be insignificant at alpha equal to 5% or 10%. The addition of the square of population served variable slightly increased the R-square value. This additional explanatory variable did not add any new information that could be statistically significant. The Translog ADD model was found to be insignificant at alpha equal to 5% or 10%. The standard errors are relatively high for each of the coefficients, including the constant. The Translog ADP model was also found to be insignificant at alpha equal to 5% or 10%. There are several reasons why these models are insignificant. These include: the functional form could be incorrect for this type of analysis, a low number of observations, or other random events which can not be determined. The Translog models reported in Table VI are aggregate models. The aggregation of treatment technologies could have caused the insignificance as well. To determine if this occurred, a dummy variable is used as an intercept shifter for observations using slow sand technology. Observations receive 1 for slow sand and 0 otherwise. If D1 is significant, then observations using slow sand technology have significantly different annual costs as compared to observations using Microfiltration and Package Plant treatment technologies. Table VII shows the results of using the D1 variable upon the aggregate Translog function. The Translog POP model did not change in terms of significance. This model was

TABLE VI

Regressions for Aggregate Translog without Dummy Variable

	POP	POPSQ	ADD	ADDSQ	ADP	ADPSQ
Coefficient	.64596 (4.637)	-.0074250 (.318)	-8.4120 (5.11)	.35060 (.201)	-1.9951 (7.640)	.092440 (.279)
Constant	8.2321 (16.77)		**62.510 (32.39)		22.452 (52.06)	
R Square	.3552		.5646		.4555	
N	13		13		13	
Implied Economies of Size	b		b		b	
Model Significance	No		No		No	

*Indicates significance at the 5% level. **Indicates significance at the 10% level. Standard errors are in parentheses.

^{b} is calculated for the Translog as 1- ∂ ln C/∂ ln q, and represents negative values (Christensen and Greene, 1976). Dependent Variable is Logarithm of Total Annual Cost. Independent Variables are in Logarithmic form.

TABLE VII

Regressions for Aggregate Translog with Dummy Variable

	POP	POPSQ	ADD	ADDSQ	ADP	ADPSQ
Coefficient	-1.3485	.13464	**-9.9424	*.41395	-5.5583	.22363
	(5.27)	(.3646)	(4.85)	(.1912)	(9.435)	(.3460)
D1	-.29860		-.387		-.23038	
	(.3537)		(.2432)		(.3381)	
Constant	15.326		*71.883		46.699	
	(18.98)		(30.73)		(64.26)	
R Square	.4085		.6604		.4822	
N	13		13		13	
Implied Economies of Size	b		c		b	
Model Significance	No		*Yes		No	

*Indicates significance at the 5% level. **Indicates significance at the 10% level. Standard errors are in parentheses.

[b] is calculated for the Translog as $1-\partial \ln C/\partial \ln q$, and indicates negative values (Christensen and Greene, 1976).

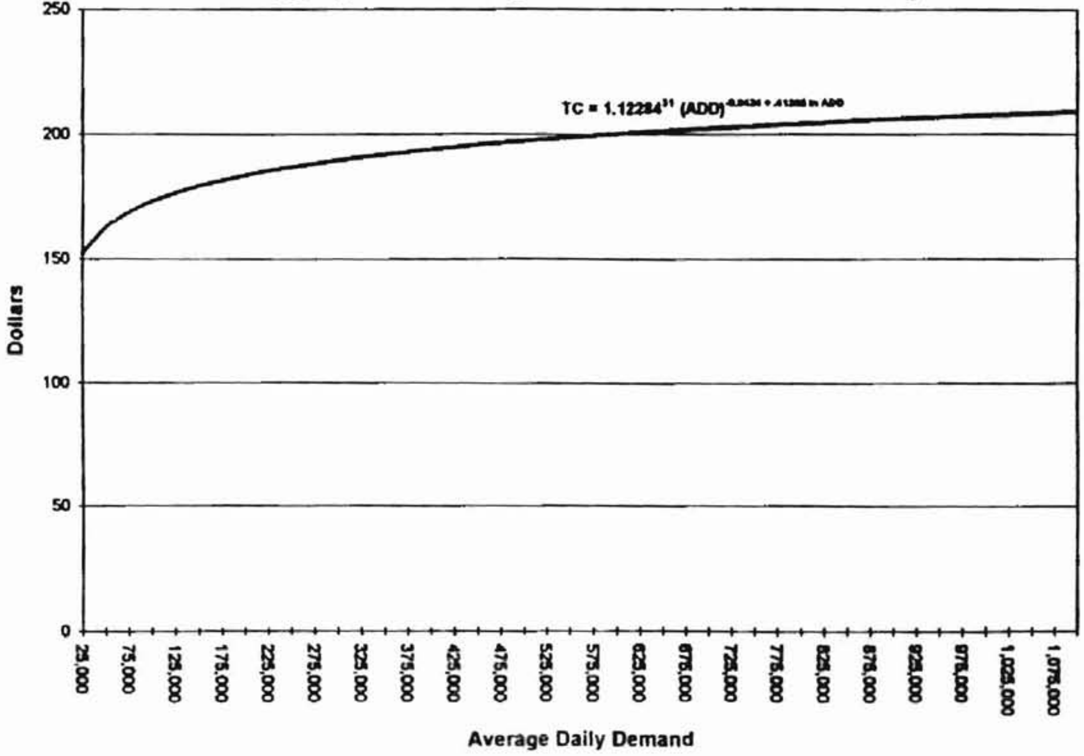
[c] is calculated for the Translog as $1-\partial \ln C/\partial \ln q$, and indicates positive values (Christensen and Greene, 1976).

found to be insignificant. The same can be said for the ADP model. The use of D1 had a different effect upon the Translog ADD model. Using the D1 coefficient lowered the standard errors associated with the ADD, ADDSQ, and the constant. All coefficients are at least 10% significant with the coefficient on ADDSQ and the constant being significant at alpha equal to 5%. The D1 coefficient is also significant at alpha equal to 10%. The significance of D1 determines slow sand technology annual total costs are significantly different from the other treatment technologies. The aggregate Translog model using ADD as the output variable and using the D1 variable can be used to estimate slow sand technology annual costs based upon ADD values. Figure 24 demonstrates the aggregate total cost equation for the Translog model using ADD as the output variable. The total cost curve increases sharply until about 525,000 gallons and then begins to level off. The economies of size for the Translog function differs from the CD model. To determine if there is economies of size present using the Translog ADD model, two methods were used. The first defines economies of size to be $1-\partial \ln C / \partial \ln q$, where q is defined as output and in this case q is ADD. If this value is less than zero, diseconomies of size are present and if greater than zero, then economies of size exist. The second method includes conducting a t-test upon the ADD coefficient. The null and alternative hypotheses for these tests are:

Ho: Diseconomies of Size ($\beta_1 > 1$)
Ha: Economies of Size ($\beta_1 < 1$).

FIGURE 24

Aggregate Translog ADD Total Cost with Dummy Variable



Conducting the first method upon the aggregate Translog model using ADD as the output variable yields a positive value. Since this value is positive, economies of size exist. The second method yields a significant t-test upon the ADD coefficient at the 10% level of significance. This also concludes economies of size do exist at alpha equal to 10%. The aggregate Translog ADD model yields a R-square of .6604. Using the D1 variable increased the explanatory power of the model from .5646 to .6604. Although this model is significant at the 5% level, the model is fragile due to the low number of observations.

There were two ways explored in which annual total costs of treatment, using the CD and Translog functional forms, were estimated. The first observed all treatments together, yielding the aggregate models without the use of D1. The second used D1 in order to test if slow sand treatment annual total costs were significantly different form the other technologies. The aggregate models, assuming the CD and Translog functional forms, are a good starting point in determining estimates of annual total cost of treatment. A more specific estimation procedure segmenting the data set by treatment technologies could yield models that estimate annual total costs even more precisely. The segmenting of observations by treatment technology lowers the number of observations, yet these estimations are worthy of observing.

Treatment Technology Estimations

Data in Table VIII shows CD slow sand technology using all output variables. Microfiltration was not included because of the low number of observations. The POP model was significant at alpha equal to 10% and the R-square value is equal to .4433. The coefficient on POP is positive and correct. As population served increases, so does total annual costs of treatment. This function exhibits decreasing returns to size because (b+c) <1. As stated previously, AC is decreasing and is above MC everywhere. The ADD model yielded a R-square value of .7190 and was significant at alpha equal to 5%. The sign on ADD is positive and correct. The ADP model yielded a R-square value of .8040 and it is the best model in terms of explanatory power. The ADP model also has the lowest standard errors associated with the estimated parameters. From a policy standpoint, the POP model could be useful in showing how annual total costs rise as output (POP) increases. The best model in terms of low standard errors and high explanatory power is the ADP model.

The CD Package Plant treatment technology models are presented in Table IX. None of the coefficients or the overall models were significant at alpha equal to 5% or 10%. The reason for this could be due to the extremely low number of observations. Even though the R-square values are modest, the overall models and their coefficients were insignificant. The same story applies for Table X. The results for the Translog slow sand technology estimations

TABLE VIII

Regressions for Cobb-Douglas Slow Sand Technology

Slow Sand		R Square	N	Implied Economies Size	Model Significance
Constant	*8.2837	.4433	7	1.75[a]	**Yes
	(2.138)				
POP	**.56992				
	(.28)				
Constant	2.9815	.7190	7	1.37[a]	*Yes
	(2.67)				
ADD	*.72830				
	(.204)				
Constant	3.4127	.8040	7	1.51[a]	*Yes
	(2.02)				
ADP	*.66011				
	(.146)				

*Indicates significance at the 5% level. **Indicates significance at the 10% level. Standard Errors are in parentheses.

[a] is calculated for the Cobb-Douglas as 1/(b+c), (Beattie and Taylor, 1993).

Dependent variable is Total Annual Cost in logarithmic form Independent variables are in logarithmic form.

TABLE IX

Regressions for Cobb-Douglas Package Plant Technology

Package Plant		R Square	N	Implied Economies Size	Model Significance
Constant	3.6421 (5.6)	.5643	4	b	No
POP	1.2532 (.78)				
Constant	6.8293 (4.47)	.4613	4	b	No
ADD	.46655 (.36)				
Constant	5.1927 (9.17)	.2495	4	b	No
ADP	.55644 (.6824)				

*Indicates significance at the 5% level. **Indicates significance at the 10% level. Standard errors are in parentheses.

b is calculated for the Translog as $1-\partial \ln C/\partial \ln q$, and indicates negative values (Christensen and Greene, 1976). Dependent Variable is Logarithm of Total Annual Cost. Independent Variables are in Logarithmic form.

TABLE X

Regressions for Translog Slow Sand Technology

Slow Sand		R Square	N	Implied Economies Size^a	Model Significance
Constant	8.5021 (24.23)	.4433	7	b	No
POP	.5089 (6.73)				
POPSQ	.00420 (.46)				
Constant	56.362 (88.05)	.7426	7	b	No
ADD	-7.5447 (13.64)				
ADDSQ	.31942 (.5266)				
Constant	29.721 (64.83)	.8118	7	b	No
ADP	-3.1937 (9.493)				
ADPSQ	.14055 (.3462)				

*Indicates significance at the 5% level. **Indicates significance at the 10% level. Standard Errors are in parentheses.

^{b} is calculated for the Translog as $1-\partial \ln C/\partial \ln q$, and indicates negative values (Christensen and Greene, 1976). Dependent Variable is Logarithm of Total Annual Cost . Independent Variables are in Logarithmic form.

TABLE XI

Regressions for Translog Package Plant Technology

Package Plant		R Square	N	Implied Economies Size[a]	Model Significance
Constant	139.03 (127.7)	.7951	4	[b]	No
POP	-36.416 (35.50)				
POPSQ	2.6147 (2.46)				
Constant	**137.13 (18.85)	.9890	4	[b]	No
ADD	**-20.794 (3.07)				
ADDSQ	**.86339 (125)				
Constant	571.55 (281.6)	.8513	4	[b]	No
ADP	-85.344 (42.70)				
ADPSQ	3.2518 (1.62)				

*Indicates significance at the 5% level. **Indicates significance at the 10% level. Standard Errors are in parentheses.

[b] is calculated for the Translog as 1- ∂ ln C/∂ ln q, and indicates negative values (Christensen and Greene, 1976).
Dependent Variable is Logarithm of Total Annual Cost . Independent Variables are in Logarithmic form.

are presented in Table X. Although their explanatory power is high, the models are not significant because of the low number of observations. The ADD model did have some significance. The constant and all coefficients were significant at alpha equal to 10%. The overall model was found to be insignificant at alpha equal to 5% or 10% levels.

The aggregate CD models fit the data relatively well. All aggregate CD models with and without D1 were significant. The CD slow sand models were all significant . If determining which model to use between the aggregate CD model using D1 or the CD slow sand treatment technology model, model selection would depend upon the criteria present. If the criteria suggested choosing the model with the highest R-square, then the CD slow sand technology estimations would be selected. If the criteria suggested choosing the model with the lowest standard errors associated with all coefficients , then the CD aggregate model using D1 would be selected. The Translog models did not perform as well as the CD models. The only Translog model that was significant was the aggregate Translog using D1. This Translog model can be used to estimate the annual costs of slow sand technology.

There are economies of size present relative to the significant models for CD and Translog functional forms. All significant models can be used to demonstrate how output changes effect the total annual cost of providing water.

Chapter VI

SUMMARY, LIMITATIONS, AND IMPLICATIONS

The availability of quality water within any community is vital for economic growth. This is especially true for rural communities due to the small population base and limiting resources. For rural areas to grow in terms of jobs and income, quality water must be readily available. Any type of threat to a rural community's water supply is of great concern for decisionmakers within the community.

Summary

One of these types of threats could be the contamination of a community's water supply by one or more contaminants. Contamination of the water supply could causes sickness or even death within the community. For this reason, water regulatory agencies monitor water systems very closely and strictly enforce the regulations. The most powerful among these regulatory forces is the Environmental Protection Agency (EPA). EPA has been delegated the responsibility of assuring compliance for water regulations ranging from the Safe Drinking Water Act (SDWA) to the Surface Water Treatment Rule (SWTR). EPA enforces compliance standards and penalizes any system if the respective system is out of compliance. EPA currently monitors for 83 contaminants ranging from organic matter to radon. Future monitoring could include adding 25 contaminants to the current list every three years. The current contaminants and the ones to be added pose massive challenges. These regulations pose an even greater challenge for small rural systems because of the inability to spread additional costs over more users. Larger systems are able to spread the additional costs over more users. For this reason, large water systems have a greater chance in meeting compliance standards as opposed to small rural water systems.

Objectives

The general objective of the study was to summarize the changes occurring with treatment technologies and demonstrate how costs for Oklahoma rural water systems are impacted as output changes. The specific objectives were to (1) identify the types of treatments used, (2) determine the capital investment for each treatment type, (3) calculate total annual treatment costs for each type, and (4) determine which measure of output is the best, and (5) test whether economies of size exist in Oklahoma rural water treatment facilities. Objectives (1) and (2) were accomplished by gathering data from a sample of Oklahoma rural water systems. Objective (3) was accomplished by summing annual capital costs together with annual operating and maintenance costs for the surveyed systems. Objective (4) was accomplished by conducting Wald statistical tests on both functional forms. To accomplish objective (5), empirical models were formulated to test whether economies of size exist for Oklahoma rural water facilities using estimation procedures such as Ordinary Least Squares (OLS) in the form of an indirect cost function. Economies of size refer to what is happening (constant, increasing, or decreasing) to costs as output expands. Determining whether diseconomies or economies of size are present aids in understanding the relationship between average cost and marginal cost of providing treated water. Diseconomies of size would indicate as output is expanded, average cost per gallon and per user cost would increase. Economies of size would indicate as output is expanded, average cost per gallon and per user cost would decrease.

Oklahoma Rural Water Systems

In the state of Oklahoma, there are 420 rural water systems which serve approximately 1,046,966 people. Oklahoma rural water systems obtain the majority of raw water from surface sources. This aids in reducing the cost of treatment. The cleaner the surface source, the less amount of treatment is required. Although obtaining raw water from a high quality source is an attractive measure for reducing the cost of treatment, it is not always available to rural systems. The ability of rural systems to acquire raw water at an adequate quality and low cost will ensure the systems short run viability. However, in the long run there will be increased costs due to the increased amount of contaminants the rural system will be required to monitor.

To meet compliance, each rural community has to select an appropriate treatment technology that is both cost effective and complies with regulations. For this study, data were gathered from 13 Oklahoma rural water systems. They serve from 400-4,500 people and their raw water source is surface water. These systems on average distribute daily approximately 500,000 gallons of treated water. These systems spend on average $324,840 annually treating water with the average cost of treatment plants equal to $1.27 million. This study provided a descriptive analysis into the general characteristics of Oklahoma rural water systems. It also identified various treatment technologies and demonstrated how costs change given changes in the size of the systems.

The overall objective provided information about the general characteristics of Oklahoma rural water systems such as size of the system and annual compliance costs. These were obtained by using the Farmers Home Administration (FmHA) forms as well as using a computer water model constructed by Cornell University to estimate operating and maintenance (O & M) costs. More specifically, the objectives were to determine the best measure of output and estimate aggregate Cobb-Douglas (CD) and Translog indirect cost equations as well as estimating individual treatment indirect cost equations under the same two functional forms. These functional forms were estimated to test the null hypothesis of diseconomies of size being present as opposed to the alternative of economies of size being present.

All aggregate CD models, using average daily demand (ADD), average daily production (ADP), and population served were significant at alpha equal to 5% with and without the use of a dummy variable. Observations using slow sand technology were given a value of 1 and all others received 0. Although these aggregate models using the dummy variable were significant, the dummy variable coefficient was insignificant at alpha equal to 5% or 10%. Due to this statistical insignificance, the valid aggregate CD models are the ones which did not employ the use of the dummy variable. For these significant models, where the estimated coefficient on output (ADD, ADP, population served) was statistically significant , economies of size exist. The presence of economies of size has implications relevant to the average cost per user/gallon. When economies of size are present, average cost per user/gallon is decreasing as output is expanded. Diseconomies of size would indicate as output is expanded, the average cost per user/gallon increases. This is not the case for the 13 Oklahoma rural water systems in this study. The 13 Oklahoma rural water systems experienced economies of size even though they are small systems. This could be attributed to many factors. These could have included: the availability of a high quality raw water source, or a low number of contaminants. The presence of economies of size was enhanced by conducting treatment technology estimations rather than aggregate estimations. These estimations also revealed the presence of economies of size.

The aggregate Translog models, using all three variables for output, were insignificant at alpha equal to 5% or 10% without the use of a dummy variable. However, when employing the use of a dummy variable, the aggregate Translog model using ADD as output became significant at alpha equal to 5%. Determining whether economies of size are present is different for the Translog as opposed to the CD. Economies of size were present for the aggregate Translog model using ADD as output because the t-test on ADD was significant at the 5% level and also $\partial \ln TC / \partial \ln ADD$ resulted in positive values for the observed ADD values. In other words, the average cost per user/gallon decreased as output expanded. The inability of the other two Translog models to estimate annualized costs significantly could have been caused by many different factors. These are discussed in the limitations segment.

The aggregate models serve as a good beginning in estimating annualized treatment costs for Oklahoma rural systems, but because treatment technologies differ, an individual treatment technology estimation approach proved more useful. The individual treatment technologies estimated were slow sand filtration and package plants. There were only seven observations used in the slow sand CD and Translog equation estimates and four used for the package plant estimation. Microfiltration was excluded because the number of observations (2) equaled the number of regressors in the Translog form. This posed estimation problems. All slow sand CD models using all three output variables were at least significant at alpha equal to 10%. The package plant CD models using all three output variables were insignificant at alpha equal to 5% and 10%. The same conclusion applies to the Translog slow sand and package plant models. The failures of the individual treatment models as well as the Translog aggregate models using ADP and population served as output could be caused by many factors.

Limitations

There are many limitations to this study. These include: small sample size, Best Available Treatment (BAT) Technology document extrapolations, aggregate treatment technologies, data source, operating and maintenance (O & M) estimates, indirect cost functional forms, and population range.

The most limiting factor is the small sample size. There were only 13 observations that met the criteria needed to conduct hypothesis tests. If the number of observations had been higher, than potentially model significance could have been higher. The BAT document originally estimated capital and O & M costs for population sizes less than 1,000. Due to lack of data on larger systems, those estimates were used to extrapolate estimates for larger than 1,000 population sizes using ordinary least squares (OLS). The reason this could be a potential problem is because the computer model used to estimate O & M costs for this study used those extrapolated BAT equations. The data collected consisted of three different types of treatment technologies. The combining of these technologies could have caused a pooling of error effect across treatment technologies. The best data for this type of estimation would be individual treatment technology costs for a larger data set. The data source (FmHA) is another limiting factor. Instead of using FmHA only, all lenders would have yielded more observations. The reason FmHA was selected is due to data availability and consistency. Operating and maintenance cost estimates could have caused errors in aggregate total costs due to the system sizes in the study being outside the range of populations the BAT equations were valid for. The BAT equations were estimated for a population size of less than 1,000. This study had a population range from 400 to 4,500. The pooling of these estimates with annual capital values could have caused an aggregate error effect for total annual costs. Imposing various functional forms could have been the reason for some of the poor model estimates. Perhaps a wider range of functional forms would have proved more efficient and useful instead of just the CD and Translog forms. Other functional forms may have yielded better models, given the economic rational is valid. The data collected represent a large range of populations from 400 to 4,500. Because the selected technologies are greatly affected by population size changes, a smaller range of populations would prove potentially to be a better estimation of costs. If the annual total cost of a population size of 1,000 is desired, then models derived from annual total cost equations less than 1,000 could potentially be more accurate than estimates derived from using a population size ranging from 400 to 4,500. In other words, the amount of error in estimating annual total costs for a population size of less than 1,000 could be less than estimating annual total costs using a wider range.

For future research, data should be gathered according to a prespecified range of populations and specific treatment technologies such as only slow sand technology. The ranges could include 100 to 1,000, or 1,000 to 2,000. The literature reviewed for this study indicates that estimates of annual total costs are best estimated by individual treatment technologies. Also, the data analysis should be expanded to include other data sources. This would potentially provide more observations and a stronger conclusive study. The reason the aggregate CD models were significant is due to the similarity of treatment methods and associated costs. To be more conclusive about economies of size and how it varies with output, more data are needed to make all the models significant and improve the estimates of annual total costs.

Implications

The SDWA and its 1986 Amendments are going to cause the costs of treatment to rise for all systems in the future because of the increase in monitoring and potential treatment efforts for more contaminants. The total cost of compliance impact of the SDWA is not the same for each system because of the unique characteristics of the rural water system and its raw water source. Compliance costs for many rural systems will be staggering due to the need for additional capital equipment used to monitor and treat the additional contaminants.

In the short run, Oklahoma rural water systems will be able to endure the increases in contaminant monitoring and testing because of the good surface water sources. Well water compliance costs will vary as well because of the location of the well within the state. The same type of relationship between raw water quality and cost of treatment holds for well water. If the well is a good quality source with a low number of contaminants, then treatment costs will not be as high as one with a poor well source.

In the long run, technological advances made in water testing may detect certain contaminants not presently found within both the well and surface water sources. This ability would cause rural and all other systems to monitor, test and potentially treat for even more contaminants. In these conditions, the increased costs may overwhelm the Oklahoma rural systems and force them to find alternative ways of providing safe drinking water for their community. Options such as consolidation or even purchasing treated water may need to be evaluated. Although these options may be cost effective, it was observed in this study that the rural systems are afraid of loosing control of their respective water supplies. Regardless of control, rural systems can only afford to pay so much for their water because of limiting resources and small populations.

In summary, rural water systems face massive challenges in complying with the SDWA and it will become increasingly important to conduct long term planning for water needs as the cost of monitoring and treatment increase due to the new regulations. To comply and to be cost effective, rural water systems will have to employ technologies that are low in capital and O & M costs. These will be determined by what type of contaminants each system will be required to monitor and potentially treat for as specified by Congress and enforced by the EPA.

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APPENDIX A

BAT DOCUMENT TECHNOLOGIES AND ASSUMPTIONS

Slow Sand Filtration

Costs

As the flow of water increases, the amount of area required (as well as capital costs) rises proportionally. There are no chemical or power costs, but sand must be increased as water flow increases. The equation in which to estimate annual O & M costs is as follows:

(26) $O \& M = 4.2 + 209.4 [LAB] [AVG]^{-1}$

where	O & M	O & M costs, cents/kgal,
	AVG	Average Daily Flow, kgpd, and
	LAB	Available labor for O & M, hrs/week.

Also, O & M costs are a function of the frequency of filter scraping. Current practice for the U.S. shows scraping to vary from monthly to semi-annually. For the above equation, a scrapping frequency of 1.5 months was used.

Design Parameter Assumptions

Filtration rate = .049 gpm/ft square.
Sand depth = 3.5 ft.
Support gravel = 1.0 ft.
LAB = .64 hrs/week.
Load Rate = .1 gm/ft square.

Microfiltration

Costs

The best application for MF is for particle removal. Using MF as a treatment option provides a high quality of water and it does not produce a chemical sludge residual which must be removed and disposed. This is extremely important for small systems, since the removal of a sludge would increase the cost of this technology. To estimate the O & M values for MF the following equation was used from the BAT document.

$$(27)\ O\ \&\ M = 129.4\,[AVG]^{-.324} + 209.8\,[LAB]\,[AVG]^{-1}$$

where	O & M	O & M costs, cents/kgal,
	AVG	Average Daily Flow, kgpd, and
	LAB	Available labor for O & M, hrs/week.

Also, membrane replacement frequency is assumed to occur every 5 years. As the membrane life increases replacement frequency decreases as does O & M cost.

Design Parameter Assumptions

LAB = 8 hrs/week
3 people per household

Package Plants (Ion Exchange)

Costs

Package Plants are pre-fabricated treatment units that arrive on site ready to use. These types of plants can use various types of methods of treatment. The ones used in Oklahoma are ion exchange units. The annual O & M cost equation used by BAT is:

$$(28)\ O\ \&\ M = 144.5\,[AVG]^{-.51} + 329\,[REG] + 209.8\,[LAB]\,[AVG]^{-1}$$

where	O & M	O & M costs, cents/kgal,
	AVG	Average Daily Flow, kgpd,
	LAB	Available labor for O & M, hrs/week, and
	REG	Regenerant usage, lb NaOH/kgal.

Design Parameter Assumptions

Liquid Loading Rate = 8 gpm/ft square

Bed Depth = 8 ft
Regenerant Requirement = 15 lb./ft square resin
Total Resin Volume/Design Flow = 2.5 minutes
Regenerant Frequency = Once per day

Additional Cost Assumptions

These assumptions pertain to the additional costs of treatment other than the estimated ones discussed above. The additional costs are made up of adding a road, pump, fence, building, land or distribution systems. The assumptions for these are as follows:

(1) The total process area is square.
(2) There is a 15 ft. process area between the process area boundary and the site boundary.
(3) The fence follows the site boundary.
(4) A 25 ft. road extends 100 ft. from the secondary road and borders one side of the site.
(5) A 75 ft. turnaround is located at the end of the road.

Each observation's characteristics were simulated within the model given all the information contained in the FmHA (RECD) forms. This was done to insure consistency and accuracy for each observation.

APPENDIX B

PROJECT SUMMARIES

Case Study No. 1: Barnsdall

Summary: Barnsdall needs no additional land; they are currently leasing enough to account for the new construction. The current distribution system is in good condition and does not require replacement at this time.

Code:	**OK-1**
Technology:	**Slow Sand Filtration**
Population served:	1,700
Median Income:	$20,676
ADP:	500,000
ADD:	350,000

Assumptions: Additional costs include a wellhead pump, fence and a road.

Total Capital Cost of Project:	$1,050,000
Year:	1994
Converted to 1992 Dollars	
Total Capital Cost of Project:	$960,750
Annual Capital Cost (trt)	$97,855
Annual O&M Cost of (trt)	$61,565
Total Cost of Treatment	$159,420

Case Study No. 2: Ketchum

<u>Summary:</u> Ketchum will acquire one acre of land for the construction of the treatment plant. This will be a stand alone system that will be connected to the Ketchum PWA system and distribution system will be replaced.

Code: OK-1
Technology: Slow Sand Filtration

Population served: 1,800
Median Income: $20,319

ADP: 350,000
ADD: 180,000

Assumptions: Additional costs include a wellhead pump, fence, road, land, and a new distribution system.

Total Capital Cost of Project: $1,880,000
Year: 1994
<u>Converted to 1992 Dollars</u>
Total Capital Cost of Project: $1,720,200

Annual Capital Cost (trt) $175,206
Annual O&M Cost of (trt) $65,870

Total Cost of Treatment $241,076

Case Study No. 3: **Stuart**

Summary: Existing system is out of compliance and proposed site will be built upon 320 acre site at a market price of $100,000

Code:	**OK-1**
Technology:	**Package Plant**
Population served:	1,224
Median Income:	$16,891
ADP:	700,000
ADD:	225,000

Assumptions: Additional costs include a wellhead pump, fence, road, and a new distribution system.

Total Capital Cost of Project:	$1,380,000
Year:	1993
Converted to 1992 Dollars	
Total Capital Cost of Project:	$1,317,900
Annual Capital Cost (trt)	$134,231
Annual O&M Cost of (trt)	$19,950
Total Cost of Treatment	$154,181

Case Study No. 4: Crowder/Canadian

Summary: Current facility can not meet compliance. The new treatment plant will be built on the same land as the old one, therefore no new land is needed for construction.

Code:	**OK-1**
Technology:	**Slow Sand Filtration**

Population served:	2,500
Median Income:	$17,694

ADP:	1,500,000
ADD:	680,000

Assumptions: Additional costs include a wellhead pump, fence, and road. No distribution system cost will be included. They will use their existing one.

Total Capital Cost of Project:	$817,000
Year:	1993
Converted to 1992 Dollars	
Total Capital Cost of Project:	$780,235
Year:	
Annual Capital Cost (trt)	$79,469
Annual O&M Cost of (trt)	$184,695
Total Cost of Treatment	$264,164

Case Study No. 5: Langston

Summary: Currently, the existing plant does not meet quality standards set by OSDH. The new facility will provide adequate and high quality water for the town of Langston. The land needed for construction has been donated by the Langston University.

Code:	**OK-1**
Technology:	**Slow Sand Filtration**
Population served:	448
Median Income:	$6,806
ADP:	300,000
ADD:	165,000

Assumptions: Additional costs include a wellhead pump, fence, and road.

Total Capital Cost of Project:	$510,300
Year:	1993
Converted to 1992 Dollars	
Total Capital Cost of Project:	$487,337
Annual Capital Cost (trt)	$49,636
Annual O&M Cost of (trt)	$36,939
Total Cost of Treatment	$86,575

Case Study No. 6: Vian

Summary: New plant is needed due to OSDH standards. The plant will consist of new raw water intake structure, plant, distiribution lines and new storage tanks. Land will be purchased for the amount of $2,500/acre.

Code:	**OK-1**
Technology:	**Microfiltration**
Population served:	1,250
Median Income:	$10,376
ADP:	1,500,000
ADD:	500,000

Assumptions: Additional costs include a wellhead pump, fence, road and a new distribution system.

Total Capital Cost of Project:	$670,000
Year:	1992
Converted to 1992 Dollars	
Total Capital Cost of Project:	$670,000
Annual Capital Cost (trt)	$68,241
Annual O&M Cost of (trt)	$113,229
Total Cost of Treatment	$181,470

Case Study No. 7: Hulbert

Summary: The new treatment facility is an automated package plant system. New distribution lines will also be installed due to leakage problems with the existing ones and land will be purchased for construction.

Code:	**OK-1**
Technology:	**Package Plant**
Population served:	2,119
Median Income:	$11,335
ADP:	1,000,000
ADD:	650,000

Assumptions: Additional costs include a wellhead pump, fence, road and a new distribution system.

Total Capital Cost of Project:	$2,032,000
Year:	1992
Converted to 1992 Dollars	
Total Capital Cost of Project:	$2,032,500
Annual Capital Cost (trt)	$207,015
Annual O&M Cost of (trt)	$478,450
Total Cost of Treatment	$658,465

Case Study No. 8: Stilwell

Summary: New standpipe, treatment facility, and distribution systems will be constructed on a newly purchased one acre of land. Existing system leaks and does not meet quality standards.

Code: **OK-1**
Technology: **Microfiltration**

Population served: 800
Median Income: $8,380

ADP: 1,100,000
ADD: 2,000,000

Assumptions: Additional costs include a wellhead pump, fence, road and a new distribution system.

Total Capital Cost of Project: $1,154,000
Year: 1990
<u>Converted to 1992 Dollars</u>
Total Capital Cost of Project: $1,211,700

Annual Capital Cost (trt)	$123,414
Annual O&M Cost of (trt)	$336,399
Total Cost of Treatment	$459,813

Case Study No. 9: Coweta

Summary: New standpipe, treatment facility, and distribution systems will be constructed on a newly purchased one acre of land. Existing system leaks and does not meet quality standards. The new facility consists of two package plants built side by side. One is to be used for current demand and the other for future demand.

Code: **OK-1**
Technology: **Slow Sand Filtration**

Population served: 3,500
Median Income: $20,299

ADP: 3,000,000
ADD: 900,000

Assumptions: Additional costs include a wellhead pump, fence, road, and a new distribution system.

Total Capital Cost of Project: $1,750,000
Year: 1990
<u>Converted to 1992 Dollars</u>
Total Capital Cost of Project: $1,837,500

Annual Capital Cost (trt) $187,153
Annual O&M Cost of (trt) $446,779

Total Cost of Treatment $633,932

Case Study No. 10: Wagoner

Summary: New standpipe, treatment facility, and distribution systems will be constructed on a newly purchased one acre of land. Existing system leaks and does not meet quality standards. Project includes 5,000 feet of new lines.

Code: **OK-1**
Technology: **Slow Sand Filtration**

Population served: 4,500
Median Income: $12,252

ADP: 2,000,000
ADD: 1,000,000

Assumptions: Additional costs include a wellhead pump, fence, road, and a new distribution system.

Total Capital Cost of Project:	$1,333,321
Year:	1990
Converted to 1992 Dollars	
Total Capital Cost of Project:	$1,469,986
Annual Capital Cost (trt)	$142,592
Annual O&M Cost (trt)	$330,100
Total Cost of Treatment	$472,692

Case Study No. 11: Jay

Summary: New standpipe, treatment facility, and distribution systems will be constructed on a newly purchased one acre of land. Existing system leaks and does not meet quality standards. Project includes 54 miles of new lines.

Code: OK-1
Technology: Microfiltration

Population served: 624
Median Income: $10,521

ADP: 1,000,000
ADD: 300,000

Assumptions: Additional costs include a wellhead pump, fence, road, and a new distribution system.

Total Capital Cost of Project: $1,714,800
Year: 1990
Converted to 1992 Dollars
Total Capital Cost of Project: $1,800,400

Annual Capital Cost (trt) $183,389
Annual O&M Cost of (trt) $73,941

Total Cost of Treatment $257,330

Case Study No. 12: **Muskogee**

Summary: New standpipe, treatment facility, and distribution systems will be constructed on a newly purchased one acre of land. Existing system leaks and does not meet quality standards. Project includes 54 miles of new lines.

Code:	**OK-1**
Technology:	**Package Plant**
Population served:	1,450
Median Income:	$10,926
ADP:	1,000,000
ADD:	450,000

Assumptions: Additional costs include a wellhead pump, fence, road, and a new distribution system.

Total Capital Cost of Project:	$420,000
Year:	1990
Converted to 1992 Dollars	
Total Capital Cost of Project:	$441,000
Annual Capital Cost (trt)	$44,917
Annual O&M Cost of (trt)	$332,150
Total Cost of Treatment	$377,067

Case Study No. 13: **Westville**

Summary: System will consist of new standpipe storage tanks, facility and new distribution system. Current system is old and increased demand for new customers warrants the new facility.

Code:	**OK-1**
Technology:	**Package Plant**
Population served:	850
Median Income:	$9,342
ADP:	300,000
ADD:	80,000

Assumptions: Additional costs include a wellhead pump, fence, road, and a new distribution system.

Total Capital Cost of Project:	$1,800,000
Year:	1991
Converted to 1992 Dollars	
Total Capital Cost of Project:	$1,854,000
Annual Capital Cost (trt)	$188,834
Annual O&M Cost of (trt)	$60,900
Total Cost of Treatment	$249,734

VITA 2

James N. Barnes

Candidate for the Degree of

Master of Science

Thesis: AN EMPIRICAL INVESTIGATION INTO THE ECONOMIES OF SIZE FOR OKLAHOMA RURAL WATER SYSTEMS

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Experience: Raised on a ranch in Soper, Oklahoma. Employed by Oklahoma State University: Department of Agronomy in Weed Science Row Crops as a graduate student assistant (5/92-5/94) and the Department of Agricultural Economics as a graduate student, 6/94 to present.

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