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ESTIMATING WATER DEMAND SCHEDULES FOR SELECTED INDUSTRIES IN ARKANSAS

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ABSTRACT

ESTIMATING WATER DEMAND SCHEDULES FOR SELECTED INDUSTRIES IN ARKANSAS

Water demand functions for the paper and chemical industries in the state of Arkansas were estimated utilizing data collected from individual plants throughout the state. Regression analysis was used to estimate demand functions from a data base which included information on intake and gross water use by source, recirculated water use, costs of acquiring, treating, and discharging water, plant output, employment, and level of technology. The demand for intake water was estimated as an exponential function of average water costs and the level of technology primarily. Price elasticities of demand were estimated as approximately equal to one for both industries. The results of this study could be used to determine the effects of various public policies on the withdrawal of water for industrial purposes.

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ESTIMATING WATER DEMAND SCHEDULES FOR SELECTED INDUSTRIES IN ARKANSAS
KEYWORDS--*water demand/*industrial water use/*elasticity of demand/*pulp and paper industry/*chemical industry/*regression analysis

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HIGHLIGHTS

The objectives of this study included an historical analysis of the scope and dynamics of water use in manufacturing industries in Arkansas and estimates of water demand functions and price elasticities of demand for the state's paper and chemical industries.

1. On the basis of very little available information it appeared that industrial water use in Arkansas has followed national trends, i.e., increases in output have exceeded those of gross and intake water, indicating that plants are using their water more efficiently in response to increased costs of acquisition, treatment, and discharge and also improvements in water saving technology. This observation is particularly true for heaviest water using industry in the state,i.e., paper.

2. Estimates of the water demand functions of the paper and chemical industries were based on a comprehensive data set which was collected by questionnaire and personal visits to plants throughout the state. Regression analysis was used to estimate exponential demand functions which initially included information on each plant's average water costs, water use, technology level, employment, and output. Only water costs and technology were statistically significant, and both were related inversely to the amount of intake water demanded.

3. Price elasticities of demand were estimated for the range of prices included in the sample, i.e., from 0.9¢/1000 gallons to 21.0¢/1000 gallons with an average of 12.6¢/1000 gallons. At the average price paid for intake water, the estimated price elasticity of demand was equal to -0.94 for chemical plants and -1.06

for paper plants. While no strict comparisons are possible because of differences in data, methodology, and time frame, these estimates are generally slightly higher than those of other studies of industrial water use and indicate that Arkansas paper and chemical industries are somewhat more responsive to the changes in water costs than is true nationally.

4. The estimated demand functions and price elasticities can be used to determine the effects on water use of various public policies which affect the costs of water used by the paper and chemical industries, such as a change in water quality standards.

CHAPTER I

INTRODUCTION

The efficient use of water resources requires a knowledge of expected water demands to help pinpoint areas which are likely to face either shortages or surpluses of water, determine the optimal price to charge various water users, and aid the impact analysis of different water policies on water use. These are areas of concern in the planning, development, and use of water resources and have been identified as such in the Second National Water Assessment. At the present time, water demand functions have been estimated for agricultural and residential users in Arkansas.[1] The purpose of the present study is to develop estimates of water demand schedules for major industrial users.[2] Estimates of industrial water demand schedules would provide a basis for both short and long term water planning and management. In the short run these estimates could be used to assess the effects on industrial water use of changes in water quality requirements, water availability, and water costs. Over the longer term they could be used to estimate future industrial water use based on various assumptions about public policies, anticipated economic growth, and

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[1] See Projected Water Requirements and Surface Water Availability for Arkansas by Shulstad, Ziegler, and Cross, for the Arkansas Soil and Water Conservation Commission, and An Analysis of Residential Water Demand Schedules in Arkansas by Ford and Ziegler, Publication 76, Arkansas Water Resources Research, 1980.

[2] In many studies, the terms water demand and water use interchangably. In this study water demand will refer to water use at a specific price and a water demand schedule or water demand function will refer to a set of water prices and corresponding estimates of water use at those alternative prices.

water costs. They provide a much more sound and versatile basis on which to forecast water use than the requirements approach which has been used in other studies.[3]

Objectives

It is not the intent of this project to develop necessarily new models or methodologies to estimate water demand schedules for all industrial users in Arkansas. Rather, it is to apply existing models, modified if necessary to account for the characteristics of Arkansas

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[3] The forecasting of future water use is not new. Most studies use a "water requirements approach" which usually combines projected economic data with estimated water use coefficients. It generally assumes that the trends which influenced water use in the past are stable and can be extended into the future. However, the quantities of water used are highly dependent on the prevailing objectives of society and upon the methods and purposes of water use, upon economic policy and other variables that can be influenced by public policy. It seems reasonable to question the usefulness of water requirements projections *per se* since these other factors are either so dominant or uncertain in the long run as to be undependable for decision. Because of the uncertainties surrounding future water policies the water requirements approach to forecasting future water use is not likely to be very reliable. Moreover, when incorporated into water planning programs it tends to result in self-fulfilling prophesies, i.e., the projected requirements are often used to generate support for specific water projects.

The present study places major emphasis on an alternative approach which analyzes the influences of the factors that control or influence the use of water. This approach deals explicitly with the determinants of water use including price and public policy. Forecasts of water demand must take into account the different values of water use for various purposes. Water does not have an unlimited economic value. Moreover, differences exist in the incremental values of water used for different purposes and water users tend to decrease their water use with increased prices for water. Reallocation of water resources can be expected to occur as the effective price of water increases. Consequently, future forecasts of water use should consider demand schedules which reflect the incremental value of water in alternative uses. These demand schedules should consider both quantity and quality characteristics since these are inseparable.

firms, to the major water using industries. These industries include paper and pulp (S.I.C. 26) and chemicals (S.I.C. 28) which together accounted for 70.3 percent of total manufacturing water use in Arkansas in 1975 (See Table 1).

The general purpose of this study is to estimate water demand schedules for these two industries considering both quantity and quality characteristics. More specifically, the objectives are to:

1. provide historical perspective on the scope and dynamics of water use in manufacturing industries in Arkansas;
2. identify the major determinants of water use for each of the manufacturing industrial groups specified above, and test the hypothesis that there are significant differences in these determinants;
3. estimate the demand schedules for each of these industries;
4. test the hypothesis that there are significant differences in the sensitivity of these water demands to changes in the cost of water.

Methodology

The procedures which will be used in this project include the use of published and unpublished information available from the U.S. Bureau of the Census, Department of Commerce, Water Resources Council, and Geological Survey and the Arkansas Industrial Development Commission, Industrial Research and Extension Center, Soil and Water Conservation Division and other federal and state agencies to provide historical perspective and also trace the dynamics of manufacturing water use in Arkansas. Analysis of this information will provide the

TABLE 1

Water Withdrawals for Selected Industries in Arkansas, 1975

Two-digit Industry Classification		Withdrawals (million gallons/year)
S.I.C. 20:	Food & Kindred Products	10,679
S.I.C. 22:	Textiles	2,760
S.I.C. 26:	Paper & Pulp	66,409
S.I.C. 28:	Chemical	31,913
S.I.C. 29:	Petroleum	7,780
S.I.C. 33:	Primary Metals	6,690
All other manufacturing		13,635
	TOTAL	139,786

Source: National Water Assessment.

necessary groundwork for both estimating present demand schedules as well as predicting future use.

In addition, models of manufacturing water use will be developed for each industry utilizing information obtained from plant visits, previous studies, public and private agencies, and expert opinion. Data requirements of the models will form the basis for the development of a questionnaire which will be administered primarily by mail to a statewide sample of establishments in the two industry groups. In order to increase the response rate second mailings, personal telephone contact, and personal visits will be utilized. After the information from the questionnaires is tabulated and coded, regression analysis will be utilized to identify the determinants of water use, the parameters of the demand schedules as well as the price elasticities of demand. Traditional statistical techniques will be used to test the hypotheses specified previously.

The next chapter of this report discusses how water is used in the various stages of manufacturing, particularly the paper and chemical industries in Arkansas. Chapter III provides an historical perspective on both the temporal and spatial variations in water use and reuse in major water using industries to determine the extent to which water use technology has been changing. Chapter IV presents a review of previous industrial water demand studies and highlights the procedures and their limitations to estimate water demand schedules empirically. This information is used to develop the methodology and data collection procedures used in this study and discussed in Chapter V. The last chapter contains the results and analysis of the industrial water demand estimates and, outlines some of the uses and limitations of the results.

CHAPTER II

HOW WATER IS USED IN MANUFACTURING PROCESSES

In order to estimate industrial water demands it is first necessary to understand how water is used in the various manufacturing processes. The identification of the uses of water in these processes will help in the specification of an industrial water demand model. The purpose of this chapter is first to describe generally how water enters into the various stages of the manufacturing process and then to describe more specifically its role in the paper and chemical industries.

Manufacturing Process

The manufacturing process can be divided into three stages, i.e., input assembly, input processing, and output distribution. Water is important in the assembly stage both as a means to transport other inputs to the point of production and also as an input itself. As an input water has such a low unit value that its transportation over any distance is not economical. Consequently, firms which use large amounts of water as input tend to locate near ample supplies of water. These locations sometimes have the added advantage of providing low cost transportation for the assembly of other inputs as well, e.g., a paper mill can use a river to obtain its water input as well as to transport its lumber. In addition water is sometimes used to transport the finished products which are generally bulky and/or have a low unit value.

Water is used in the input process stage in a variety of ways, e.g., for cooling, or conveyance of other inputs, or as part of the finished product. Its use in the production process is determined by the nature of the production function, cost, and technology. Consider, for example a class of production functions given by:

$$q = e^t x_1^{\alpha},\ x_2^{\beta} \qquad \alpha, \beta > 0 \text{ and } \alpha + \beta < 1 \tag{2-1}$$

where q = output,
e^t = level of technology, and
x_1, x_2 = inputs 1 and 2 respectively.

A producer will face a profit function equal to:

$$\pi = pe^t x_1^{\alpha} x_2^{\beta} - r_1 x_1 - r_2 x_2 \tag{2-2}$$

where p = output price
r_1, r_2 = input prices

A profit maximizing producer will use each input up to the point where the value of its marginal product (VMP) equals its price (r) or, put another way, the producer can increase profit as long as the addition to revenue in employing an additional unit of input exceed its cost. Consequently, an input demand function can be derived by first taking partial derivatives of the profit function with respect to each input and setting the equation equal to zero and then solving for x_1, and x_2, or:

$$\frac{\partial \pi}{\partial x_1} = p\alpha e^t x_1^{\alpha-1} x_2^{\beta} - r_1 = 0 \tag{2-3}$$

$$\frac{\partial \pi}{\partial x_2} = p\beta e^t x^{\alpha}{}_1 x_2^{\beta-1} - r_2 = 0 \tag{2-4}$$

and,

$$x_1 = \left[\frac{\alpha}{r_1}\right]^{(1-\beta)/(1-\alpha-\beta)} \left[\frac{\beta}{r_2}\right]^{\beta/(1-\alpha-\beta)} \left[e^t p\right]^{1/(1-\alpha-\beta)} \tag{2-5}$$

$$x_2 = \left[\frac{\alpha}{r_1}\right]^{\alpha/(1-\alpha-\beta)} \left[\frac{\beta}{r_2}\right]^{(1-\alpha)/(1-\alpha-\beta)} \left[e^t p\right]^{1/(1-\alpha-\beta)} \tag{2-6}$$

From (2-5) and (2-6) it can be seen that the demand for each input is inversely related to input prices and technology and positively related to output prices.

These results imply that if water is an input in the production process described by (2-1) its use would tend to decrease as it became more costly, technology increased, and/or the price of other inputs decreased. Over the past thirty years water has become more expensive and, as will be seen in the next chapter, its use per unit of output has been falling. On the basis of our production function model this observation could be the result of higher water prices and/or higher levels of technology. In addition, it could be the result of relatively higher prices of non-water inputs. Ceteris paribus, an increase in the price of these inputs will increase the use of water if water can be used as a substitute for these other inputs. If water is a complement to these other inputs, however, its use will also decline in response to an increase in the price of these other inputs.

It should be clear that changing water use can be due to a variety of factors and that producers can respond in a variety of ways to changing water costs. The importance of these various factors and the producers' response to them depends on the characteristics of specific industries. In order to estimate water demand functions for the paper and chemical industries it is necessary to modify the general model discussed above to take account of the different ways water enters into the manufacturing process. The remainder of this chapter contains an outline of the general production process in the paper industry and selected chemical industries with a more detailed description of the use and reuse of water in the input process stage.

Paper and Pulp Industry[1]

The paper and pulp industry in the state of Arkansas has a wide variety of final products. There are seven relatively large paper mills in Arkansas providing the industry with products ranging from fine paper for copying machines to newsprint and paper bags. Common to all of the paper and pulp plants is the demand for large quantities of cooling and process water, e.g., it is not uncommon for some of the larger plants to have an intake of fifty million gallons per day. Because of this extraordinary demand for water, paper and pulp plants are usually located near major surface water as their primary water source, some utilize deepwater wells where water table conditions allow cheap abstraction.

Paper and paper products are manufactured from wood pulp derived from raw timber. Most Arkansas paper and pulp plants transform raw timber into debarked wood chips which are fed into a digester where they are steamed and then cooked in a solution consisting of caustic soda and sodium sulfide known as white liquor. Once the cooking process is completed, the chips are "blown" from the digester to a tank where they separate into fibers or pulp. Steam from the tank goes to an accumulator for heating process water. The pulp is then transferred, along with the spent cooking liquor known as black liquor, to a brown-stock chest and then on to a vacuum drum washers where

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[1] Portions of the text on pulping and papermaking were obtained from the following source: Develoment Document for Effluent Limitations Guidelines (BPCTA) for the Bleached Kraft, Groundwood, Sulfite, Soda, Deink, and Non-Integrated Paper Mills Segment of the Pulp, Paper, and Paperboard Point Source Category, United States Environmental Protection Agency, December, 1976, pp. 63-72 and pp. 84-88.

countercurrent washing separates the black liquor from the pulp. Generally, the pulp will be washed three times as it is rolled through the washers, while the black liquor is allowed to fall into a recovery trough. The black liquor is then burned as fuel in a boiler. While burning of the concentrated liquor occurs, organic sodium compounds are converted to soda ash and the molten smelt of salts are dissolved in water to form green liquor. The green liquor is causticized with lime to convert the soda ash to caustic soda. The caustic soda is then combined with sodium sulfide to produce white liquor which is settled, filtered, and adjusted to the correct strength so it can be used in the cooking process described earlier. The settling of white liquor produces lime mud which is washed, dewatered, and burned in rotary kilns to form quick lime. The quick lime is then hydrated with green liquor for reintroduction into the recovery cycle.

After being separated from the black liquor during the washing process, the pulp is diluted and screened to remove incompletely cooked chips and other residues incompatible with bleaching, which is the next stage in the manufacturing process. Bleaching is usually performed in stages which are designed to brighten the pulp and preserve pulp strength, consistency, and process temperature. At each stage the pulp is bleached with a chemical agent, such as chlorine, for a specified amount of time. The number of bleaching stages vary depending on the desired brightness of the pulp, e.g., the bleaching process is very intensive for high grade fine paper while it may be nonexistent for brown paper bags. Once the pulp has been treated, it is sent to a papermaking process or to a pulp dryer where it can be used in the production of some other product.

In the papermaking process pulp is resuspended in water to a consistency of four to six percent. The stock is brushed with mechanical beaters for the purpose of obtaining matting which provides the strength of the paper. The amount of brushing varies with the degree of quality required for the products.

Upon refinement, the stock is cleaned, screened, and introduced to a fourdrinier headbox where the pulp flows onto a wire screen to form a paper sheet. A suction pick-up roll transfers the sheet from the wire to the pressses which enhance density and remove additional water. The sheet is then placed in dryers and converted into the final product.

Quite obviously, water is a very important input in the papermaking process and is subject to intensive reuse due to the fact that lower grades of water quality are acceptable to a succession of uses within the overall process. Initially water is taken from some outside source and treated, if necessary, for use in processing. Process water is used to separate pulp from spent cooking liquor during the pulp chemical recovery process. It is also used for secondary clarification, additional washings, filtration of unusable residue from the pulp, and as an aid for sludge removal. During the actual papermaking process, water is used to suspend the pulp stock, and to aid in further pulp washing and screening. Much of the process water can be recycled provided that sufficient removal of dissolved solids occurs through discharge or demineralization. For example, boiler feed water requires intensive demineralization in order to avoid mineral buildup on the sides of the boiler itself. Such a buildup will result in shut-down of the boiler which in turn will require some plants to shut down entirely.

Water used for cooling purposes does not require the intense prepatory treatment necessary for processing water. Cooling water only requires settling and the addition of biocides and anti-corrosives. The water is then utilized in a variety of cooling functions: Heated cooling water is usually treated in induce-draft evaporative cooling towers. Such towers have a fan at the top of the tower slots in the tower. Once treated, the cooling water is ready for discharge or more commonly, recycling.

Chemical Industry

The production process used in the paper and pulp industry is very similar between plants and, consequently, relatively simple to describe. The chemical industry, however, includes a broad range of inputs, products, and processes; and is more difficult to model. In fact, it has been noted that ". . . the chemical industry is as diverse as any industry could be and still have a general title." For this reason this study will concentrate on the industrial inorganic (S.I.C. 281) and agricultural chemical (S.I.C. 287) industries in Arkansas. Many of the chemicals produced in the state are used in the

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[2] Portions of the text on various chemical production processes Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Basic Fertilizer Chemicals Segment of the Fertilizer Manufacturing Source Category, U.S. Environmental Protection Agency, March 1974, pp. 53-63, and Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Major Inorganic Products Segment of the Inorganic Chemicals Manufacturing Point Source Category, U.S. Environmental Protection Agency, March 1974, pp. 51-55.

manufacture of fertilizers, e.g., ammonia, nitric and sulfuric adic, ammonium nitrate, and urea. In addition, bromine and alumina chemicals are produced for use in non-agriculture industries. The production process for each of these chemicals will be discussed in turn.[2]

Ammonia

Ammonia is the base component for the entire nitrogen fertilizer industry. It is produced in larger quantities than any other inorganic chemical except sulfuric acid. Because it is such a necessary part of nitric acid, ammonium nitrate, and urea, ammonia plants are often located on the production site of one of these other chemicals.

Ammonia is produced by the reaction of hydrogen with nitrogen in a three to one volume ratio. The raw material source for nitrogen is atmospheric air, while hydrogen is commonly obtained from natural gas sources. In order to produce ammonia it is necessary to product syn gas (make-up gas) at the front end of the production process. Many ammonia plants use steam-methane reforming units to produce this gas. The steam-methane process begins with the removal of sulfur from the natural gas hydrogen source. The natural gas is mixed with steam at high temperatures (1450° F) and undergoes what is known as a shift reaction which results in the oxidation of hydrogen (thus allowing the

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[2] Portions of the text on various chemical production processes were obtained from: Development Document for Effluent Limitations Guidelines and New ource Performance Standards for the Basic Fertilizer Chemicals Segment of the Fertilizer Manufacturing Source Category, U.S. Environmental Protection Agency, March 1974, pp. 53-63, and Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Major Inorganic Products Segment of the Inorganic Chemicals Manufacturing Point Source Category, U.S. Environmental Protection Agency, March 1974, pp. 51-55.

hydrogen molecules to be free) along with the creation of carbon dioxide. Following the shift conversion, the gas is transferred to a carbon dioxide recovery section where a circulated solution reacts with the gas steam to reduce carbon dioxide levels. Additional carbon dioxide is removed when the gas is passed through a nickel catalyst. After cooling the syn gas is ready for compression and feeding to the ammonia synthesis section.

Syn gas is used as make-up feed to the ammonia synthesis section. The reaction of nitrogen and hydrogen is carried out in the presence of an iron promoted metal oxide catalyst at elevated pressure, which favors the ammonia formation, in a special reaction vessel called a converter. The conversion process generates a large quantity of reaction gas (hydrogen, nitrogen, methane, argon, other inerts, and ammonia) which is cooled to condense the ammonia. It is then recompressed, mixed with fresh make-up gas, and reheated for use in the ammonia converter.

Water is essential to the ammonia process because of the steam reaction which must take place for natural gas sulfur removal. Cooling water is utilized in the syn gas process immediately after carbon dioxide removal and just before compression. The hydrogen and nitrogen react in the ammonia converter and are then passed on to the condenser. The liquid ammonia product, which is 80 percent process water, is then stored in large atmospheric tanks at sub-zero temperatures.

Nitric Acid

Nitric acid is one of the nitrogenous fertilizers produced in Arkansas' chemical industry. As with other nitrogen based fertilizers, nitic acid requires ammonia as a basic ingredient. In almost all cases, ammonia is produced at the nitric acid production site.

Nitric acid is produced by the ammonia oxidation process. In this process, ammonia is mixed with air to produce oxides of nitrogen. Further oxidation is followed by the introduction of water which yields the final nitric acid product (the fertilizer industry uses a 55% to 65% dilute acid).

The initial ammonia oxidation (a mixture of ammonia and compressed air) takes place in a converter at high pressure. The hot exit gases from the converter are used to super heat steam and preheat process air. The removal of steam cools the nitric oxide to the point where secondary oxidation starts taking place. Upon completion of the secondary level of oxidation, the gases are fed into an absorption column. At the same time that the gases are fed into the absorption-column, process water (which acts as an asbsorbant) is fed into the top of the column. Nitric acid is removed from the bottom of the column.

In the nitrogen fertilizer industry (as with other organic chemicals) water is an essential part of the chemical process. In its final form, nitric acid requires process water for dilution and absorption. Water is also utilized as a coolant in the ammonia absorption process. Finally, as with most heavy industrial water users, steam is generated in boilers for the purpose of driving compressor turbines. In Arkansas, almost all of the nitric acid plants (and plants producing other nitrogen fertilizers) obtain their water from deep wells. Because treatment costs of groundwater are substantially less than surface water, the nitrogen fertilizer firms tend to prefer well water to surface sources.

Ammonium Nitrate

Ammonium nitrate is another member of the nitrogen fertilizer product group. It is a popular fertilizer due to its high nitrogen content and relatively low cost. Ammonium nitrate is produced by reacting ammonia with nitric acid in a low pressure vessel called a neutralizer. The high heat of reaction causes flash vaporation of water leaving behind a liquid product which is 83% by weight ammonium nitrate. This product can be sold directly or processed into a dry product.

If a dried product is desired, then the liquid form either can be prilled or crystallized. If prills are desired, a concentrated form of liquid ammonium nitrate is pumped to the top of a tower where it is sprayed downward into a rising flow of air. The ammonium nitrate droplets solidify before they hit botton. The solid droplets are then allowed to cool before being coated with an anticaking agent. If a crystalline ammonium nitrate product is desired, then the concentrated liquid solution is fed into a continuous vacuum evaporator. As the liquid solution cools, crystals are formed, dried, and coated with an anti-caking agent.

Water is primarily used in this process as a coolant in the prill and crystal processes. In addition, water vapor coming from the neutralizer process is condensed and clarified in the cooling water before eventual blow-down.

Urea

Urea is a widely used nitrogen fertilizer. The process requires the reaction of ammonia with compressed carbon dioxide to form ammonium carbonate which is then dehydrated to form urea. Urea can then be sold as a liquid product or transformed into prills or crystals via a flash evaporator and prilling tower. As is the case with ammonium nitrate and nitric acid plants, urea producers will make ammonia feedstock at the same site. The ammonia plant also supplies high purity carbon dioxide necessary for urea production.

Urea plants use water for cooling, in process, and in boilers. Cooling water is introduced to the urea process during the high temperature reaction of carbon dioxide and ammonia. Generally, fans are placed at the top of the tower to draw air through the sides for the purpose of cooling the water as it moves through interior slots within the tower.

Because ammonia is 80% water, a great deal of process water is included in the urea process. Process water is removed from the urea product during dehydration and evaporation (evaporation is also necessary if solid urea products are desired). Urea plants also supply their own boiler feed water requires extensive demineralization treatment. Waste removal treatment usually consists of clarification and settlement before effluent is subjected to disposal.

Sulfuric Acid

Sulfuric acid is generally utilized as an intermediate product for other manufacturing processes, e.g., it primarily supplies the fertilizer, petroleum refining, and explosives industries, and is also used in the production of synthetic plastics, detergents, nuclear fuels, and other organic and inorganic chemical products.

Sulfuric acid is produced primarily by the contact process, which involves the burning of sulfur to sulfur dioxide, followed by the catalytic oxidation of sulfur dioxide to sulfur trioxide which is reacted with water to produce sulfuric acid.

Usually sulphur dioxide is obtained from the introduction of oxygen to pure sulfur. The contact process exposes sulfur dioxide to heated air, which in turn is introduced into a reactor containing a platinum or vanadium pentoxide catalyst. The resultant gas mixture is cooled in an absorption tower where the sulfur trioxide is absorbed by oleum (acid plus excess sulfur trioxide). After a portion of the sulfuric acid is drawn off for sale, the remaining acid is diluted and recirculated through the absorption towers, where oleum reabsorbs sulfur trioxide thus repeating the process.

Like urea plants sulfuric acid plants utilize water in process, for cooling, and in boilers. Process water is used to dilute a portion of the sulfuric acid for the purpose of recirculation through the absorption process. In addition, process water is mixed with sulfuric acid to reach desired final product levels. Acidic strengths range from about 30 percent sulfuric acid for battery acid to 70 percent for oleum. Non-contact cooling water is used in the absorption towers to cool the sulfur trioxide to the point where it is absorbed by oleum. Finally, water is used for boiler feed steam electric generation. Of course, boiler water is subject to demineralization in order to prevent buildup along boiler walls. A mineral coating would effectively insulate the boiler thus curtailing its ability to create steam.

Alumina Chemicals

Alumina chemicals are produced in large quantities in Arkansas. This is due to the fact that accessible bauxite deposits, which are an essential raw material for the production of alumnia, are located near Bauxite, Arkansas. The unique properties of alumina chemicals make them valuable as intermedidate products for other industries. For example, alumina hydrate is used as a flame retardant in carpets and drapes. Higher quality hydrates are added to fine papers as a filter to increase brightness. Calcified aluminas are used for the fabrication of high strength ceramics (chinaware, electronic components, ceramic ball bearings).

The alumina chemical process begins with the blending of bauxite ore. The bauxite is fed to a digester to begin what is called the Bayer process. The digester joins the bauxite slurry with hot sodium aluminate liquor. This mixture is heated under pressure to 300° F. The reaction causes alumina hydrate in the bauxite to form additional sodium aluminate in the liquor. After digestion, liquor and muds are separated by process water counter-current washers where 90% of the strong liquor is returned to the Bayer liquor stream. The remaining Bayer liquor is taken through a series of cooling water heat exchanges and fed to precipitators, which are large tanks holding approximately 200,000 gallons of liquor. The tanks are partially filled with liquor and then seeded with aluminum hydrate seed particles. Percipitation causes a solid alumina trihydrate to be formed.

The course hydrate is moved through a two-step counter-current washing system in order to further separate hydrate from spent liquor.

The spent liquor is fed to evaporators where water added in the process is removed. This concentrated liquor can then be reused in the process.

The washed hydrate is fed to calcifying kilns where all other moisture is dried out by temperatures of 2100° F. The product which is discharged from the kiln is alumina. The alumina chemicals are then stored in silos for shipment.

Water is essential to the alumina chemical process. It provides boiler water for plant power generation as well as cooling water for heat exchangers in the Bayer process. Process water is necessary for mud preparation, liquor separation, and precipitation. Alumina chemical plants intensively reuse their water because of valuable chemicals which can be recovered from process water and used again in the process.

Bromine

The bromine industry is concentrated near Magnolia and El Dorado in the southern and southwestern sections of Arkansas. This area of the state contains the second richest bromine formation in the world, the Smackover Formation. Brominated compounds are used in a variety of final compounds, including an antiknock compound for ethyl gasoline and flame retardants for clothing.

The process for extraction of bromine molecules is common on an industrywide basis. Generally, sodium bromide brine is pumped out of the highly porous bromine formation and transferred to a container. Process water is used to produce steam which is injected along with chlorine into the container holding the sodium bromide. The sodium bromide then reacts with the steam and chlorine to produce sodium chloride (salt). The chlorine frees the bromine ion which in turn joins with other bromine ions to form a bromine molecule. The structural properties of this molecule allow to join with a variety of other elements to produce several chemical compounds.

Many of the bomine product processes generate extreme amounts of heat, e.g., upon extraction the sodium bromide brine is 190° F. Much of the water used in bromine plants is for cooling. All plants in Arkansas used non-contact cooling water via heat exchangers. Cooling water is intensively recycled through cooling towers. Reuse is both economically and environmentally important. Water is disposed of through injection wells back into the formation. In fact, in some cases disposal water may be used to exert additional pressure on the brine formation, thus making extraction easier. This secondary recovery method is somewhat similar to the water injection process employed by the petroleum industry.

Summary

Water is an important input in the production of paper and various chemicals in Arkansas. It is used and reused in a variety of ways - reflecting various levels of sophistication for the production of boiler steam, for cooling purposes, and in process. Because of its multiple uses plants could respond in a variety of ways to increases in cost and technology. Specifically how they have responded to these changes is the subject of the next chapter.

CHAPTER III

CHANGING WATER USE

Water is used in the industrial manufacturing process in all three general stages of production, i.e., the procurement and processing of inputs, and the distribution of output. Like other nontransferable inputs used in the productive process, changes in the relative cost of water should change the relative amounts used. But because of the spatial variations in the costs of water, these relative price changes can result also in locational shifts of major water using industries over time. As water becomes increasingly scarce and more costly the question of whether, and to what extent, industries respond through changes in their productive processes and/or changes in location becomes more important in determining the future growth and development of many communities. The purpose of this chapter is to provide an historical perspective on temporal and spatial variations in water use and reuse in major water using industries to determine the extent to which water use technology has, in fact, been changing.[1]

The basic data for the analysis is taken from the United States Bureau of the Census on water use in manufacturing for the years 1954,1959, 1964, 1968, 1973, and 1978. The Census data include information on intake and gross water use for all manufacturing establishments reporting over 20 million gallons of intake water per year. Water use in manufacturing in the United States in concentrated in four two-digit industries, i.e., paper (26), chemicals (28), petroleum (29), and primary metals (33), which in 1978 accounted for nearly 85

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[1] A similar, more dated, study can be found in <u>Changing Water Use in Selected Manufacturing Industries</u> by Robert A. Leone, J. Royce Ginn, An-Loh Lin, NBER, 1974.

percent of water withdrawals by all major water users in manufacturing. Only these industries will be anaslyzed.

In addition to intake (IW) and gross water (GW) use two other measures will be used in this analysis. In order to correct for the effects of output changes on water use both changes in intake and gross water will be adjusted by changes in output as measured by real value added, i.e., nominal value added adjusted by the appropriate industrial wholesale price index.[2] Another measure used in this analysis is the reuse factor which indicates the number of additional times a gallon of intake water is reused and is computed as the difference between gross and intake water divided by intake water. Generally, increasing reuse factors indicate improvements in water use technology but decreasing factors don't necessarily imply the opposite. For example, the reuse factor can decrease if a substitute for water is used in the cooling process but water use technology is improved because both gross and intake water use would be reduced.

National Variations in Industrial Water Use

As indicated in Exhibit 3-1 there is wide variation in the use of intake water per dollar of real value added among the two digit industries and also within each industry grouping. Moreover, this ratio declined almost without exception between 1954 and 1973. In analyzing the latter phenomenon it is useful to think of IW/VA as the product of GW/VA and IW/GW, where GW equals gross water, GW/VA

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[2] The 1978 data does not include value-added by manufacture for each of the water using industries. Consequently, some of the following analysis is limited to the 1954-1973 time period.

EXHIBIT 3-1

Intake Water Per Real Dollar Value Added, Selected U.S. Industries

SIC INDUSTRY	1954	1959	1964	1968	1973
26 PAPER	5201	491	512	458	424
2611 Pulpmills	NA	1255	716	1207	1139
2621 Papermills, Except Building paper	NA	600	625	529	544
2631 Paperboard Mills	NA	624	538	523	446
28 CHEMICAL	439	338	304	277	202
2812 Alkalies and Chlorine	1610	1515	1362	1000	903
2815 Cyclic Intermediates and Crudes	NA	312	207	227	NA
2818 Industrial Organic, N.E.C.	NA	801	701	631	NA
2819 Industrial Inorganic, N.E.C.	2601	453	318	292	190
2821 Plastics Materials and Resins	21	142	195	162	109
2823 Cellulosic Manmade Fibers	94	424	428	362	NA
2824 Organic Fibers, Noncellulosic	48	121	108	129	127
2871 Fertilizers	432	392	631	487	NA
29 PETROLEUM	721	434	427	306	399
2911 Petroleum Refining	611	517	428	312	408
33 PRIMARY METALS	339	251	373	347	370
3312 Blast Furnaces and Steel Mills	309	443	516	486	531
3313 Electrometallurgal Products	1443	1403	NA	1811	NA
3334 Primary Aluminum	766	401	393	257	225

Source: U.S. Department of Commerce, Bureau of the Census, Census of Manufacturers, Water Use in Manufacturing, 1954, 1959, 1964, 1968, 1973 editions.

measures the productivity of water[3] and IW/GW measures the intensity of water recirculation. As shown in Exhibit 3-2 the GW/VA ratios have declined generally in the paper, chemical, and petroleum industries, and increased in the primary metals industry between 1954 and 1968 or, put somewhat differently, water has become more productive as an input in the former industries and less productive in the latter industry. Curiously, the GW/VA ratios increased in all two-digit industries between 1968 and 1973.

Between 1954 and 1978 the ratio of IW/GW decreased continuously for almost every industry listed in Exhibit 3-3. This downward trend is much more evident than it was for the GW/VA ratio, and indicates the increase in economic and technological feasibility of recirculating water in the productive process. Recirculation was greatest in the petroleum industry due, in large part, to its extensive use of water for cooling purposes. Recirculation also was high in the paper industry but most probably for different reasons, i.e., pulp mills in particular use relatively expensive chemicals which, when recovered, allow for the reuse of water. The reuse of water was relatively low in the chemical industry which not only tends to use a large amount of water for cooling but also tends to use considerable amounts in processing and in the final product. Quite obviously the latter two uses tend to lower the amount of recirculation.

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[3] Gross water is that amount of water required if no water was reused in the production process and enters the production function as an input. Thus, the reciprocal of gross water per dollar of real value-added (where real value added is used as a proxy for output) stands for the productivity of water.

EXHIBIT 3-2

Gross Water Per Real Dollar Value-Added Selected U.S. Industries

SIC INDUSTRY	1954	1959	1964	1968	1973
26 PAPER	13363	1532	1491	1326	1425
2611 Pulpmills	NA	3705	2288	3623	4112
2621 Papermills, Except Building paper	NA	1853	1699	1383	1634
2631 Paperboard Mills	NA	2048	1719	1759	1811
28 CHEMICAL	783	545	592	583	1110
2812 Alkalies and Chlorine	1798	1692	1620	1486	1208
2815 Cyclic Intermediates and Crudes	NA	552	530	498	NA
2818 Industrial Organic, N.E.C.	NA	1175	1363	1168	NA
2819 Industrial Inorganic, N.E.C.	5535	1051	837	813	583
2821 Plastics Materials and Resins	21	332	420	351	921
2823 Cellulosic Manmade Fibers	171	851	657	781	NA
2824 Organic Fibers, Noncellulosic	174	188	228	318	335
2871 Fertilizers	523	654	1212	2029	NA
29 PETROLEUM	2146	1903	1877	1563	2537
2911 Petroleum Refining	2044	2276	1895	1589	2579
33 PRIMARY METALS	434	384	553	539	662
3312 Blast Furnaces and Steel Mills	390	677	746	734	887
3313 Electrometallurgal Products	1765	1520	NA	1944	NA
3334 Primary Aluminum	993	690	669	644	924

Source: U.S. Department of Commerce, Bureau of the Census, Census of Manufacturers, Water Use in Manufacturing, 1954, 1959, 1964, 1968, 1973 editions

EXHIBIT 3-3

Ratio of Intake to Gross Water Use, Selected U.S. Industries

SIC INDUSTRY	1954	1959	1964	1968	1973	1978
26 PAPER	.43	.32	.34	.34	.30	.19
2611 Pulpmills	.39	.34	.31	.33	.28	.35
2621 Papermills, Except Building paper	NA	.32	.37	.38	.33	.14
2631 Paperboard Mills	NA	.31	.31	.30	.25	.21
28 CHEMICAL	.63	.62	.51	.48	.38	.35
2812 Alkalies and Chlorine	.91	.90	.84	.44	.75	.51
2815 Cyclic Intermediates & Crudes	.75	.57	.39	.38	NA	NA
2818 Industrial Organic, N.E.C.	.70	.68	.52	.54	NA	NA
2819 Industrial Inorganic, N.E.C.	.47	.43	.38	.36	.33	.56
2821 Plastic Materials & Resins	.55	.43	.46	.46	.28	.19
2823 Cellulosic Manmade Fibers	.55	.50	.65	.46	NA	.58
2824 Organic Fibers, Noncellulosic	.28	.65	.47	.41	.38	.30
2871 Fertilizers	.83	.60	.52	.24	NA	NA
29 PETROLEUM	.30	.23	.23	.20	.16	.14
2911 Petroleum Refining	.30	.23	.23	.20	.16	.14
33 PRIMARY METALS	.78	.65	.68	.64	.56	.52
3312 Blast Furnaces & Steel Mills	.77	.66	.69	.66	.60	.61
3313 Electrometallurgal Products	.90	.92	NA	.93	NA	NA
3334 Primary Aluminum	.68	.58	.59	.40	.24	.52

Source: U.S. Department of Commerce, Bureau of the Census, Census of Manufacturers, Water Use in Manufacturing, 1954, 1959, 1964, 1968, 1973 and 1978 editions.

In analyzing the relative importance of the GW/VA and IW/GW ratios in influencing the use of intake water per dollar of value added it is useful to examine changes between 1954-1968 and 1968-1973. In the former time period it appears that the relative importance of both factors varied among the paper, chemical, and petroleum industries but that GW/VA exerted the dominant influence in the primary metals industry. During the lattter time period GW/VA appeared to be the dominant factor in influencing the amount of intake water in all two-digit industry groups and in most four-digit industries.

Regional Variations in Industrial Water Use

Water is concentrated not only within a few industries but also within regions for different types of industries. Moreover, there are wide variations among the regions in the use of both intake and gross water per dollar of value added within each major industry group. As shown in Exhibit 3-4, for example, IW/VA varied from 31 in the Missouri region to 1651 in the Arkansas region. A closer examination of the table will reveal similar variability in other industries. As expected, this ratio declined in all industries over the past ten years but results varied by region.

One way in which these reductions in intake water have been achieved is through the increased recirculation of water. As shown in Exhibit 3-5 the levels of water reuse in 1978 tended to be higher for the pertroleum industry and lower for primary metals, higher in water scarce regions and lower elsewhere. These reuse ratios indicate the additional intake water necessary to maintain the existing level of production in the absence of any recirculation e.g., the ratio of

EXHIBIT 3-4

Regional Variations in Intake Water Per Real Dollar of Value-Added, Selected Two Digit Industries

REGION	IW/VA - 1973				IW/VA - 1973 ÷ 1964			
	26	28	29	33	26	28	29	33
New England	675	148	92	63	1.065	.731	NA	.564
Mid Atlantic	253	86	1820	336	.618	.653	NA	.934
South Atlantic	461	130	91	120	.684	.660	.448	.612
Great Lakes	228	143	374	517	.389	.558	1.723	1.181
Ohio	217	204	185	362	1.028	.511	.722	.857
Tennessee	420	324	NA	137	.792	.952	NA	1.278
Upper Mississippi	210	91	120	104	.504	.732	1.111	.353
Lower Mississippi	360	659	783	NA	.897	1.139	.738	NA
Missouri	31	62	199	116	.160	.159	NA	.997
Arkansas	1651	91	97	441	1.526	.334	1.047	NA
Texas Gulf	405	369	NA	NA	NA	.479	NA	NA
Lower Colorado	NA	146	NA	78	NA	NA	NA	.646
Great Basin	NA	643	98	108	NA	NA	NA	1.161
California	379	69	269	66	1.388	.634	.845	1.589
Columbia	667	280	65	186	.813	1.551	.772	1.186
United States	424	202	399	370	.827	.665	.934	.992

Source: U.S. Department of Commerce, Bureau of the Census, Census of Manufacturers, Water Use in Manufacturing, 1954, 1959, 1964, 1968, 1973 editions.

EXHIBIT 3-5

Regional Variations in Water Reuse Ratios, Selected Two Digit Industries

REGION	Reuse Ratio - 1964				Reuse Ratio - 1978			
	26	28	29	33	26	28	29	33
New England	1.196	.328	NA	.381	.501	NA	.667	NA
Mid Atlantic	3.271	.432	1.337	.285	NA	1.079	1.201	NA
South Atlantic	1.799	1.157	11.600	1.770	3.345	3.045	12.738	3.667
Great Lakes	1.290	.438	1.332	.318	2.187	.730	2.368	.636
Ohio	2.259	.681	6.355	.335	8.977	.976	9.342	.491
Tennessee	1.133	.694	NA	2.600	4.465	1.162	.573	7.263
Upper Mississippi	1.082	1.516	12.411	.788	1.137	1.364	23.310	1.111
Lower Mississippi	1.719	1.252	1.541	NA	1.210	1.922	2.893	NA
Missouri	4.000	2.429	NA	.643	NA	28.561	22.306	7.650
Arkansas	4.757	10.656	18.607	NA	21.649	4.683	6.121	1.176
Texas Gulf	NA	.881	5.504	1.238	10.078	2.937	13.599	NA
Lower Colorado	NA	NA	9.000	8.455	NA	NA	NA	8.392
Great Basin	NA	NA	8.500	6.000	NA	NA	21.619	NA
California	3.500	2.639	3.064	10.071	4.774	4.471	5.303	.809
Columbia	1.935	1.167	17.000	.395	3.105	.383	NA	.251
United States	1.910	.948	3.407	.481	4.298	1.889	5.982	.910

Source: U.S. Department of Commerce, Bureau of the Census, Census of Manufacturers, Water Use in Manufacturing, 1954, 1959, 1964, 1968, 1978 editions.

4.298 for the paper industry in 1978 indicates that an additional intake of 4.298 gallons of water would be required for each gallon actually withdrawn in order to satisfy gross water needs in the absence of recirculation. As expected, the reuse of water increased almost without exception across industries and regions between 1964 and 1978. Unlike the use of intake water per dollar of value added, the use of gross water changed very little over the past decade as shown in Exhibit 3-6. Obviously the observed increase in recirculation has been the major factor responsible for the reduction in the use of industrial intake water.

Industrial Water Use in Arkansas

The analysis of industrial water use in Arkansas is limited by a general lack of data. Primary data sources include the United States Geological Survey and the United States Bureau of the Census, but only the Census data is disaggregated by industry. However, even this data is not consistent over time, precluding an extensive time series analysis. The information which is available and will permit comparisons with national and regional data is presented in Exhibit 3-7.

An examination of this data reveal several important points. First, while the reuse ratio declined for all industries from 7.09 in 1968 to 1.84 in 1973, it was the result of a decrease in IW/VA which exceeded the decrease in GW/VA. As noted earlier, a decrease in the reuse ratio cannot be interpreted unambiguously as a decrease in the efficiency of water use. In Arkansas the decrease in the ratio was accompanied by an increase in water use efficiency. Second, the use of water in the production process varies widely among industries in

EXHIBIT 3-6

Regional Variations in Gross Water Per Real Dollar of Value-Added, Selected Two Digit Industries

REGION	GW/VA - 1973				GW/VA - 1973 ÷ 1964			
	26	28	29	33	26	28	29	33
New England	1256	153	126	102	1.132	.569	NA	.670
Mid Atlantic	754	188	4220	479	.429	.996	2.087	1.038
South Atlantic	1716	653	1398	666	.913	1.535	.554	1.232
Great Lakes	702	280	1363	775	.629	.748	.960	1.343
Ohio	685	44	1746	609	.992	.066	.927	1.079
Tennessee	1935	624	NA	350	1.705	1.083	NA	.904
Upper Mississippi	573	254	1849	392	.659	.808	1.273	.741
Lower Mississippi	1041	1428	3926	NA	.945	1.017	2.672	NA
Missouri	112	418	1462	168	.116	1.202	NA	.876
Arkansas	448	1091	2561	893	.265	.343	1.409	NA
Texas Gulf	3075	1275	NA	NA	NA	.826	NA	NA
Lower Colorado	NA	505	NA	513	NA	NA	NA	.507
Great Basin	NA	778	9990	858	1.875	NA	11.570	1.313
California	2294	332	1564	261	1.062	.869	1.209	.572
Columbia	2557	559	1516	463	NA	1.429	1.712	2.121
United States	433	202	399	370	NA	NA	NA	NA

Source: U.S. Department of Commerce, Bureau of the Census, Census of Manufacturers, Water Use in Manufacturing, 1964 and 1973 editions.

EXHIBIT 3-7

Industrial Water Use in the State of Arkansas

S.I.C. INDUSTRY	1973			1968		
	IW/VA	GW/VA	REUSE RATIO	IW/VA	GW/VA	REUSE RATIO
20	69.6	120.6	0.73	80.0	97.9	0.22
22	45.3	59.5	0.31	NA	NA	NA
24	159.6	176.4	0.11	56.3	95.2	0.69
25	9.4	9.4	0.00	NA	NA	NA
26	340.3	1128.5	2.32	347.2	3147.0	8.06
28	114.8	252.9	1.21	76.2	486.7	5.39
29	51.7	1206.9	22.33	NA	NA	NA
30	13.3	64.0	2.80	NA	NA	NA
31	26.4	143.4	4.50	NA	NA	NA
32	55.4	161.7	1.92	35.2	55.3	0.57
33	20.9	23.9	0.10	NA	NA	NA
34	NA	NA	NA	19.2	19.2	0.00
36	5.1	9.4	0.86	9.2	11.1	0.20
ALL	91.5	259.9	1.84	106.7	864.7	7.09

Arkansas in terms of importance in the productive process and also intensity of recirculation. Water is an important input in the paper, chemical, and petroleum refining industries as evidenced by the high ratios of GW/VA in 1973. However, there does not appear to be a positive relationship between GW/VA and the reuse ratio. The low reuse ratio for the chemical industry might be explained in part by the fact that much of the water is consumed as part of the chemicals and cannot be reused (see Chapter II).

The paper and chemical industries are the two largest users of water in the state. They used 48.2 and 10.8 billion gallons of intake water respectively in 1973, which represented 72 percent of the state total of 81.9. By national standards Arkansas is not a major user of water for industrial purposes, but the available evidence suggests that water is used more efficiently in the production process than it is nationally for the paper and chemical industries. A comparison of Exhibits 3-4, 3-6, and 3-7 shows that in 1973, Arkansas chemical firms used 114.8 gallons of water to produce one dollar of real value-added while the national average was 202. The respective figures for the paper plants was 340.3 for Arkansas firms and 424 for U.S. firms. It should be noted that these figures do not unambiguously support the hypothesis that Arkansas' chemical and paper plants use water more efficiently than similar U.S. firms in terms of lower ratios of IW/VA. The ratios could be the result of a different composition of firms which is not picked up at the two digit industry level. However, even when Arkansas firms are compared to firms within the Lower Mississippi region where most of the paper and chemicals are produced, Arkansas firms used less IW/VA in 1973.

Conclusions

The data presented here, even though highly aggregated, make clear that there has been a significant amount of technological change which has occurred since 1954 when the first water use census was taken. This observation suggests that marginal shortages of water can be tolerated by the major water using industries. Subject to technological and economic constraints. Further, there is little question that firms respond to changes in water costs and technology and that this response is significant both over time and at any one point in time.

These observations suggest that preductions of future demands for industrial water should incorporate factors which account for the ability of industries to respond to cost and technological changes. Although industrial water demand forecasting has moved in this direction during the past decade it is likely that industrial water demand predicted on the basis of current price response coefficients will tend to overstate actual future demands to the extent that future technology continues in the water saving direction. While this type of methodology is an improvemment over previous techniques, future efforts should be directed toward a fuller elaboration of industry response to changes in technology and input prices.

CHAPTER IV

PREVIOUS INDUSTRIAL WATER DEMAND STUDIES

In many instances, heavy water using firms use water from a self-supplied source such as a nearby lake, river, or well, and do not purchase it from any private or public source; self-supplied firms do not pay a market determined price. The absence of a market price raises a problem in estimating industrial water demand functions, i.e., a water demand function cannot be estimated without knowledge of water prices. The purpose of this chapter is to review and analyze previous industrial water demand studies to determine how other authors treated this and other estimation problems. This information will be used to develop and estimate the water demand models discussed in the next two chapters.

The use of cost as a price proxy variable finds its roots in a 1958 article by E. F. Renshaw[1] who hypothesized that the value of water in the industrial production process was based upon the cost of water per acre-foot in industry and estimated that domestic water had the highest value per acre-foot ($2.63), with industrial water ranked second ($1.05). The major flaw in the Renshaw study is the fact that only municipal cost sources were considered. Because self-supplied industrial water sources were not considered, it is likely that an upward bias existed in the estimate of the acre-foot cost of industrial water. In most cases, industrial firms can supply their

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[1] E. F. Renshaw, "Value of an Acre-Foot of Water," <u>Journal of Americal Water Works Association</u>, 1958.

own water inputs more cheaply than they can purchase water from some municipal source, e.g., data from the National Association of Manufacturers indicates that water derived self-supplied systems costs between one and fifteen cents per thousand gallons while water purchased from utility companies averages ten to thirty cents per thousand gallons.[2]

In a 1966 study, Kaufman and Nadler analyzed the results of a comprehensive study on mineral industry water use. They hypothesized that there was an inverse relationship between new water use and the price of water, but their results indicated there was no such relationship. Regression analysis revealed an R^2 of .44 for the explanation of the variation of total water use due to the amount of processed crude material. This implied that water was not considered to be a significant portion of total input costs. The major weakness of the Kaufman and Nadler study, like that of Renshaw, is the use of the price of purchased water as the price variable in the model.[3] Since much of industrial water is self-supplied, a municipal water market price may be inappropriate.

One of the most comprehensive studies of industrial water demand estimation can be found in a 1966 article by Blair T. Bower, who examined some of the independent variables needed to determine an

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[2] Everard M. Lofting and H. Craig Davis, "Methods for Estimating and Projecting Water Dmands for Water-Resources Planning," Climate, Climatic Change, and Water Supply, National Academy of Sciences, 1977, p. 53.

[3] Lofting and Davis, p. 53.

industrial water demand function.[4] His article suggested that the water utilization pattern for a given production unit was subject to several factors contained in a joint function which included variables on water intake, water recirculation, technology of the production process, the physical layout of the plant, and availability of places for final disposal of wastes.[5]

Bower also observed some of the specific relationships which exist between the cost of intake water and the level of recirculation in the production process. He found that the most common response for an increase in the cost of intake water was an increase in the level of recirculation.[6] Bower also examined the recirculation cost curve structures which face heavy water using industries. He hypothesized that four primary factors contributed most to recirculation costs: (1) the complexity of the production process in terms of component processes and units involved, (2) the spatial layout of the production process, (3) the range of products within the plant, and (4) the extent of water quality degradation in the production process.[7] On the basis of data from the mining and petroleum refining industries, Bower concluded the firms with relatively complex production processes, large spatial layouts, and a large range of products were

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[4] Blair T. Bower, "The Economics of Industrial Water Utilization," Water Research, A.V. Kneese and S.C. Smith, eds., Resources for the Future, Inc. (1966) pp. 143-175.

[5] Bower., p. 153.

[6] Bower., p. 167.

[7] Bower., p. 163.

characterized by increasing average and marginal costs. The relatively simple production processes tended to experience constant levels of water recirculation costs.

In a 1966 study Joe S. Bain, Richard E. Caves, and Julius Margolis hypothesized that industry would respond to increases in the price of water.[8] They stated that "the response to the demand to a change in the price of water may take place rather slowly over time, because replacements of existing facilities to facilitate the use of a different type of water may be deferred until existing facilities are nearing their normal replacement dates."[9] In noting that reaction time is sometimes slow, the authors recognized one of the biases associated with the use of cross-sectional data. Specifically, because reaction to increases in the price of industrial water may require a considerable time lag, the use of cross-sectional data may result in more inelastic measures of the price elasticity of demand for industrial water. Time series data would eliminate this problem to some degree by allowing the data base to reflect changes in water capital equipment in response to changes in price. However, there are also drawbacks with the use of time series data which will be discussed later in this chapter.

Again, the price of industrial water was considered to be only the price paid for purchased water from municipalities, in spite of the

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[8] Joe S. Bain, Richard E. Caves, and Julius Margolis, Northern California's Water Industry, Resources for the Future, Inc., (1966), pp. 183-184.

[9] Ibid., p. 184.

fact that a substantial number of industries in the study region of Northern California used self-supplied water. This situation was dismissed by the authors who stated that no good measure of self-supplied water use was available at the time.

In a 1969 study of the industrial demand for water in England, Judith Rees[10] discussed the use of cost as a price variable in regression analysis. She observed that privately abstracted water (self-supplied) systems produced a situation which the market mechanism failed to allocate supply optimally due to externalities caused by the interdependency among users. The private cost of any withdrawal is the pumping and piping cost associated with obtaining, treating, reusing, and disposing of intake water. Divergences between private and social cost occur because the individual firm does not consider the exclusion of an alternative use of water and the increased extraction costs which are imposed on other users as a result of its withdrawals.[11] Ideally, the price of self-supplied water should eliminate externalities by reflecting opportunity cost as well as private costs.

The Rees study hypothesized that industrial water use was sensitive to changes in price. The hypothesis was tested using multiple regressions which combined employment, tonnage of raw materials, age of firm, price of purchased water, and cost of abstraction as

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[10] Judith Rees, Industrial Demand for Water: A Study of South East England. London: Lowe and Brydone Printers Ltd., 1969, p. 56.

[11] Judith Rees, p. 22.

independent variables. The multiple regression for all industries in Southeast England yielded and R^2 of 0.35. When the regressions were run for specific industry groups the R^2s improved greatly and ranged from 0.37 to 0.97.

The author recognized that a large number of heavy-water using firms were located in the study area. Two price variables were used, i.e., the price of purchased water and the price of self-supplied water as measured by the average abstraction cost. The results of the analysis showed significant relationships for both price variables with relatively high levels of explanation. It was concluded that firms with available self-supplied systems had more elastic demand curves for purchased water.

As was mentioned, externalities associated with the abstraction of self-supplied water require the addition of opportunity cost to the private cost of abstraction. The English River Authority imposed a licensing system intended to internalize social costs but which, in fact, tended to prevent an optimal allocation of water resources. The system imposed an identical fee on all abstractors with the exception of agricultural and domestic users, who were exempt from the fee. Consequently, some abstractors were charged more than their opportunity costs while others were charged less.[12]

A 1969 study by H. D. Bramer and D. J. Motz incorporated a detailed questionnaire into the analysis of industrial water demand among heavy water-using industries (steel, chemicals, petroleum, and

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[12] Judith Rees, pp. 22-23.

paper).[13] The authors hypothesized, among other things, that increased production would result in increased reuse of water. They estimated that total water costs in the paper industry increased 19.7% in response to a 50% increase in production and concluded that this decrease in total water cost/unit of output was the result of an increase in reused water since reused water was considered to be a cheap substitute for new intake water. They found similar results for other industries. The results implied that heavy water-using firms were very conscious of changes in the cost of water as an input, and, therefore, the use of cost as a surrogate for price was justified since it led to a very significant (though usually inelastic) estimation of demand elasticity for industrial water.[14]

The evidence presented by Bramer and Motz don't necessarily support their conclusions. For example, their conclusions imply that recirculated water is the only substitute for intake water. Subsequent studies have shown that labor is also substitutable for intake water inputs.[15] Since the study noted changes in the production, it is reasonable to assume that the time frame of the study was adequately long enough to allow a change in the production mix. Assuming an increase in the unit cost of intake water a substitution of labor (not just recirculated water) for intake water could have been responsible for the reduction of total water costs.

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[13] Henry C. Bramer and Donald J. Motz, The Economic Value of Water in Industrial Uses. A Report Submitted to the Office of Water Resources Research, (December 1969), pp. 76-97.

[14] Bramer and Motz, p. 68.

[15] Grebenstein and Field, pp. 228-232.

In 1970, Jacob DeRooy published a doctoral dissertation on the subject of industrial water demand.[16] His discussion of an appropriate price proxy variable for self-supplied water provides an important theoretical point for the present study. DeRooy suggested that industrial water demand regression analysis should incorporate an average cost proxy variable for price. The price variable was calculated as the sum of three unit costs: the weighted unit cost of intake from both municipal and nonregulated sources, the unit cost of any treatment prior to use, and the unit cost of effluent disposal. The definition of price as the average cost of industrial water was justified on the grounds that "since the product is 'internally consumed' there is no need to be concerned with market demand in the usual sense. Demand and supply within the same firm will always be identical."[17] In industrial demand curve estimation, researchers who use cost as a proxy for the price of industrial water must assume that each firm within an industry faces a homogeneous set of cost conditions. This action justifies the estimation of an industry cost curve. If average cost is internally generated by the firm, then it is implied that the industry average cost curve is a line which connects internally generated input demand and supply equilibrium points for each firm within the industry. The connection of the equilibrium points for the various firms within the industry constitutes an industry cost curve.

16DeRooy dissertation.

[17] DeRooy dissertation, p. 51.

In 1974, DeRooy published an article which dealt with the price responsiveness of heavy industrial users of water.[18] The article, as did the author's dissertation, hypothesized that industry was responsive to changes in the price of water. A two-stage regression model was run (the independent variables were gross water use, the average cost price proxy of gross water, output, employment, and technology) for 30 chemical plants. The results showed that industrial water use was in fact responsive to changes in the price of water. Price elasticity measurements for cooling, processing, and steam generation were -.894, -.354, and -.590, respectively. Although all measures were inelastic, the author pointed out that the elasticities exceeded the expectations of water resource planners who had assumed in the past that industry users were insensitive to changes in the price of water.

DeRooy's dissertation literature review provided two additional citations which are of relevance to this study. In 1962 F.M. Fisher estimated the demand for electricity in the U.S. using the public market price for electricity as the price variable.[19] DeRooy argued that the public market price was not the price that would bring about firm response. Instead, profit maximizing firms would respond to relative changes in private costs and would not be concerned with public opportunity cost considerations. DeRooy stated that ". . . if

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[18] DeRooy article, pp. 403-406.

[19] F. M. Fisher, A Study in Econometrics: The Demand for Electricity in the United States. Amsterdam: North-Holland Publishing Co., 1962, pp. 120-149.

public rates or prices decrease, they (firms) will not necessarily switch to market electricity since they are effectively locked in by their capital investment."[20] The lack of substitutability between public and self-supplied electricity can be carried over to industrial water usage. Like electricity, large amounts of capital equipment are required for firms that supply their own water. In the short run, changes in the price of purchased water relative to sulf-supplied water prices may not have any effect on self-supplied firms because they are effectively locked into a self-supplied system. However, if the price of purchased water continued to present an attractive alternative to self-supplied water, then firms might switch to purchased water supplies in the long run.

In a 1968 article Baxter and Rees observed differences in the degree of input substitution between labor-intensive and capital-intensive firms.[21] The authors hypothesized that electricity was a substitute for labor and a complement to capital. The results of the multi-industry study indicated that the price of electricity was not significant with respect to short run changes in electrical usage. This was explained by evidence showing that there were fewer opportunities for substitution in labor-intensive firms, where electricity was locked into costly capital equipment. That is, a wider variation in electricity usage occured among capital-intensive firms, since electricity was considered a complement of capital goods consumption.

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[20] DeRooy dissertation, pp. 61-62.

[21] E. Baxter and R. Rees, "An Analysis of the Industrial Demand for Electricity," The Economic Journal, (June 1968), pp. 277-296.

CHAPTER V

METHODOLOGY AND DATA COLLECTION

The purpose of this chapter is to detail the methodology which is used to estimate water demand functions for the paper and chemical industries in Arkansas. In particular, it discusses the selection of an appropriate production function, the equational form of the necessary cost and demand functions, and the independent variables. In addition, it discusses data selection and collection issues, including the use of cross-section data, questionnaire design, and data collection problems. The last section of the chapter presents sample tests and discusses the jackknife procedure as it applies to this study.

Nature of the Production Function

One of the necessary considerations for input demand estimation is knowledge of the firm's production function. Evidence presented in the previous chapter suggested that water was a substitute for labor but a complement to capital. Because it is likely that the elasticities of substitution among these three inputs are not identical, a production function which permits multiple elasticities of substitution would be appropriate.

Relatively simple production function models are not capable of reflecting different elasticities of substitution between inputs. For example, the Cobb-Douglas production function assumes a constant elasticity of substitution which is equal to one for all inputs. A pure CES production function assumes a constant elasticity of substitution among all inputs, although the elasticity coefficient doesn't necessarily have to be equal to one. A production function developed by Uzawa, however, permits varying estimates of the elasticies of substitution between different sets of inputs. Thus relatively higher elasticities of substitution can be assumed between labor and water, while reltively lower elasticities of substitution can be assumed between capital and water. The Uzawa function is given by:

$$q = (\alpha_1 IW_1^{-\beta_{12}} + \alpha_2 K_2^{-\beta_{12}})^{-\rho_{12}} (\alpha_3 M_3^{-\beta_{34}} + \alpha_4 L_4^{-\beta_{34}})^{-\rho_2/\beta_{34}}, \tag{5-1}$$

where

q is a measure of output;

α_i is the input intensity parameter constant reflecting positive marginal products which decrease monotonically throughout the range of input values;

β_{ij} is a substitution constant that represents the degree of substitutability among inputs within a specific input subset;

ρ_i is also a substitution constant which describes the degree of input substitutability;

and

IW, K, L, and M are intake water, capital, labor, and materials, respectively.

The partial elasticities of substitution are

$\sigma_{12} = 1/1 + \beta_{12}$, $\sigma_{34} = 1/1 + \beta_{34}$.

The Uzawa model assumes a production function which is homogeneous of degree one, has diminishing returns to all inputs, and constantly diminishing marginal rates of technical substitution.[1]

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[1] C. E. Ferguson, <u>The Neoclassical Theory of Production and Distribution</u>, London: Cambridge University Press, (1969) p. 110.

It can be argued that the Uzawa function is weakened by the assumption of homogeneity of degree one. However, C.E. Ferguson suggests that homogeneity of degree one should be assumed when cross-section data is used.[2] Specifically, data which covers a relatively short time span will probably not reflect significant changes between input groups. In the case of cross-sectional data, Ferguson finds that production functions assumed to have homogeneity of degree one provide a better statistical fit when compared to functions showing increasing returns to scale.

Econommic efficiency requires that cost is minimized for the production of each level of output. In this study total production cost (C) is equal to:

$$C = p \cdot IW + g \cdot Mq + w \cdot lq + r \cdot Kq \tag{5-2}$$

where

p is the unit cost of obtaining, treating prior to use, and disposing of industrial water,

g is the unit price of materials,

w the wage rate, and

r the rate of return to capital.

Cost and Demand Functions

It is useful to express algebraically the relationships between the total cost and intake water dependent variables and their respective independent variables. On the basis of previous studies and economic theory, the following relationships will be estimated:

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[2] C. E. Ferguson, "Substitution, Technical Progress, and Returns to Scale," American Economic Review, Papers and Proceedings, LV, pp. 304-305.

$$IW = f(ACIW, DTECHO, EMPLOY, AVDPROD, COOLPER, AGEPE, GWIWRAT, DTYPE) \quad (5\text{-}3)$$

and

$$TCI = f(SQIW, DTIW, APIW, EMPIW, DTEKIW, AGEIW, TEMPIW). \quad (5\text{-}4)$$

Exhibit 5-1 gives a detailed description of each variable with respect to its measurement as well as its expected effect on the dependent variable.

The price variable (ACIW) is expected to have an inverse relationship with the dependent variable (IW) on the basis of traditional economic theory. The technology dummy variable (DTECHO), is also expected to vary inversely with IW. This hypothesized relationship is based on the expectation that overall improvements in technology are likely to result in more efficient use of intake water as water saving capital equipment is used.

The percentage of gross water used as cooling water (COOLPER) is expected to vary inversely with IW because firms which use a high percentage are more likely to reuse large amounts of water. In the past, firms have found that it is relatively cheaper to recirculate cooling water than it is to obtain fresh intake; thus firms with high COOLPER values are likely to have proportionately reduced intake water needs.

It is expected that the amount of intake water will vary directly with the average age of the plant and equipment (AGEPE). In the past the cost of obtaining suitable water for production purposes was relatively low; thus older plants and equipment were not constructed to reuse water intensively. Accordingly, firms with older plant and equipment can be expected to require more intake water than their modern counterparts.

EXHIBIT 5-1

List of Variables With Expected Signs

Variable Name	Description of Measurement	Expected Sign (+ or -)
Quantity of intake water (IW)	Amount of intake water obtained from all sources in gallons per day	(+) when IW is used as a dependent variable in the total cost function
Total cost of intake water (TCI)	Dollar amount of daily intake water cost. Calculated by multiplication of average cost of intake water (ACIW) by IW	TCI is a dependent variable only
Average cost intake water (ACIW)	The average cost of intake water (obtaining, treating, and disposal) in cents per thousand gallons of intake water	(-)
Technology (DTECHO)	Dummy variable obtained by assigning "0" to old levels of technology and "1" to all other levels of technology	(-)
Total plant employment (EMPLOY)	Number of people employed in each plant	(+)
Average daily production (AVDPROD)	Average daily production in tons per day	(+)
Cooling water as a percentage of gross water (COOLPER)	Obtained by dividing total average daily intake (IW) into average daily intake for cooling purposes	(-)
Average age of plant and equipment (AGEPE)	An estimate of the age of plant and machines	(+)
Gross water-intake water ratio (GWIWRAT)	Measured by dividing IW into total daily gross water	(+)

EXHIBIT 5-1 (Cont.)

Variable Name	Description of Measurement	Expected Sign (+ or -)
Type of plant (DTYPE)	Dummy variable distinguishing between paper = 0 and chemical = 1	(-)
DTIW	Independent variable obtained by the multiplication of IW times DTYPE	(-)
APIW	Independent variable obtained by the multiplication of AVDPROD times IW	(+)
EMPIW	Independent variable obtained by the multiplication of EMPLOY times IW	(+)
DTEKIW	Independent variable obtained by the multiplication of DTECHO times IW	(+)

Note: In parts of chapters V and VI, the letter "L" appears in some of the regression equations. The letter "L" denotes the logarithmic transformation of the variable, i.e., LIW is the log base ten of IW.

The GWIWRAT variable refers to the ratio between the daily quantity of gross water, which is equal to intake water times the number of reuses, and the daily quantity of intake water; that is, it represents the intensity of water reuse. The higher the ratio, the more intensively intake water is reused. If all other factors are held constant, plants with relatively high GWIWRAT ratios should require roportionately less intake water than plants with lower GWIWRAT figures. Plants which require large amounts of intake water such as paper mills are expected to be more sensitive to the costs of obtaining water and, consequently, as IW increases GWIWRAT should increase and vice versa.

The type of firm (paper or chemical) is indicated by a dummy variable (DTYPE) and is expected to vary inversely in relationship with IW because Arkansas paper plants use relatively daily volumes of intake water than chemical plants. It is assumed that the DTYPE variable will have a negative sign since paper plants are assigned a value of zero and chemical plants are equal to one.

It should be noted that no variable was chosen to represent the price of other inputs. Although knowledge of the prices of other inputs may be relevant to long-term decision-making, it is not important for short-run time framework in which the prices of other inputs are held constant. This assumption greatly simplifies the data requirements of the study. If the prices of other inputs are assumed to change, then extensive (and often unobtainable) knowledge of input cross elasticities would be required for input demand estimation.

Each independent variable for the intake water total cost function (TCI) is obtained by the multiplication of IW times the value of the original variable (for example, EMPIW, is equal to EMPLOY times IW, and so on). SQIW or IW^2 is expected to vary directly with TCI since TCI varies directly with IW. DTIW is expected to vary inversely with TCI since paper plants generally use more intake water than plants. EMPIW is expected to vary directly with TCI because the level of plant employment is considered to be a proxy of plant size and as plant employment (and plant size) increases, so too will the total cost of intake water. DTEKIW is assumed to vary inversely with TCI. Plants with "old" levels of technology are expected to have higher total water costs than plants with "average" or "advanced" technology.

Data Type and Collection

This study uses cross-section rather than time series data for several different reasons. It is relatively easier to obtain the necessary response about current conditions than historical ones. Secondly, the sample is made up of paper and chemical plants that produce several different products. Given the heterogeneity of the sample, a single set of equations taken from a narrow group of variables does not cover adequately the wide variety of respondent producers. Instead, the application of cross-section data seems more appropriate since it utilizes information from a broad spectrum of individual firms so that industrial water use may be described by a single general set of equations.

Generally, cross-section data has been treated as superior to time-series data for the estimation of water demand.[3] Kindler and

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[3] Janusz Kindler and Blair T. Bower, "Modelling and Forecasting of Water Demands," submitted for presentation at the Conference Application of Systems Analysis in Water Management Budapest, 28-29 November 1978, p. 19.

Bower point out that cross-section data contain large variable variations while time-series variations may only be slight over time.[4] DeRooy pointed out that the Baxter and Rees study may be biased due to the use of time-series data. Baxter and Rees concluded that electricity use is not responsive to price changes when large amounts of capital are present. Since sample capital stock changed very little over the eleven year data collection period, DeRooy concluded that the cross-price elasticity estimates were biased. He further stated that deployment of cross-section data would have eliminated the time-series bias by allowing for greater variations in the capital stock variable.[5] Lastly, time-series data are more likely to have serially dependent (autocorrelated over time) variables. The problem of autocorrelation does not exist in cross-section data use, since order of observation is not relevant.

Once the data needs of the study were determined, a preliminary questionnaire was sent to six sample plant environment supervisors across the state (three questionnaires were sent to paper and pulp plants, two questionnaires were sent to inorganic chemical plants, and one questionnaire was sent to a fertilizer chemical plant). Accompanying each questionnaire was a cover letter which stated the purpose of the study and the need for respondent cooperation. The questionnaire mailing was followed by a series of personal interviews with each firm's environmental supervisor in order to seek advice from respondents on questionnaire clarity and to gain familiarity with each

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[4] Kindler and Bower, p. 20.

[5] DeRooy dissertation, pp. 69-70.

industry's water use process. Generally, respondents were quick to point out unanswerable questions as well as to suggest ways to improve the questionnaire.

After the interview process, demand model requirements were reviewed along with suggestions from each interview which resulted in the final questionnaire. The questionnaire was divided into four parts:

(1) general plant information,

(2) output and technological considerations

(3) nature of water use, and

(4) water cost information.

A copy of the questionnaire along with descriptive statistics can be found in Exhibits 5-2 and 5-3.

The data for this study was obtained from responses to a questionnaire which was sent to the 23 paper, inorganic chemical, and agricultural chemical plants in Arkansas. Although the paper, chemical, steel, and petroleum industries are major industrial water users in the U.S., Arkansas has only one oil refinery and no steel production plants.

After the final questionnaires were mailed to each plant (along with a cover letter and self-addressed, stamped envelope) interviews were set up with thirteen of the largest plants in order to encourage a high response. The response rate for firms that granted interviews after final mailing was 91%. The plants which were not visited required an average of four follow-up telephone calls before responses were returned. It should also be noted that firms receiving only

EXHIBIT 5-2

QUESTIONNAIRE

University of Arkansas
Department of Economics
Rm. 402 Business Administration Bldg.
Fayetteville, Arkansas 72701

(THIS INFORMATION WILL BE TREATED WITH THE UTMOST CONFIDENTIALITY)

Date ____________________

Firm Name and Address ____

Person providing data ______________________ Phone No. ______________

1. Which one of the following groups does your firm fall into? Check the appropriate box.)

   Paper and Pulp

   Inorganic Chemicals

   Agricultural Chemicals

   Other (Please elaborate in the space provided) _____________

2. Please indicate the year on which the data is based _____________

3. Plant employment _________ (Enter total number of plant employees)

4. What product(s) does your plant produce mainly? _________________

5. Average daily production _______ (Enter your plant's average daily production in tons/day or some other common measure used in your industry)

6. Number of production days/years ______ (Enter your plant's number of production days per year)

7. Level of technology: Old Average Advanced
   (Please check the appropriate box basing your response upon your best estimate of your plant's technology relative to other plants in the industry)

8. In what year was your plant built? ______ Have you added on or modernized the plant since that time? _____ If yes, what would you estimate as the average age in years of the plant and equipment?
   ____

9. Intake (GPD) _______
   Enter the total volume of water taken into the system from all sources (e.g., sources would include public water systems, company surface of groundwater systems, etc.) in gallons per day.

10. Of the total intake water specified in Question 9 what amount in gallons per day is used for the following purposes:

    Cooling (GPD) ________

    In Process (GPD) ________

    Other (GPD) ________ (Other would include sanitation, drinking water, etc.)

    NOTE: The sum of the water used for cooling, in process, and other purposes should equal the intake water figure specified in Question 9.

11. How much of the intake water specified in Question 9 does your plant obtain from the following sources?
    A. Public system (GPD) _______
    B. Company system (GPD) _______
        a. Company goundwater (GPD) _______
        b. Company surface water (GPD) _______

    NOTE: Answers a and b should add up to the total company system water specified in part B of this question.

12. How much water does your plant discharger per day? (GPD) ________ Include all water brought to the ultimate discharge point whether treated or not.

13. Gross water use (GPD) ___________ Enter the total volume of water used in gallons per day. Gross water use is defined as the total volume of water through all individual uses, that is, intake times the number of reuses (Gross water use would be the amount of intake water your firm would require if it did not recirculate or reuse any of the intake water).

14. Of the total gross water specified in Question 13 what amount in gallons per day is used for the following purposes?

    Cooling (GPD) ________

    In Process (GPD) _______

    Other (GPD) _______

    NOTE: The sum of the water used for cooling, in process, and others should equal the gross water figure specified in Question 13.

15. Water use equipment as a percentage of total capital equipment________ Please indicate the percentage of water use equipment cost outlay in relation to total capital equipment cost outlay. (Water use equipment cost outlay is defined as the equipment necessary to obtain water, treat water prior to use, and the treatment of water prior to disposal, including waste treatment).

16. Total cost of obtaining intake water $________.
(Please indicate total direct and indirect costs, including capital costs, in cents per thousand gallons).

17. Total cost of treating intake water prior to use $_______ (Please indicate the total direct and indirect costs, including capital costs of treating water prior to use in cents per thousand gallons).

18. Total cost of reusing or recirculating water $_______(Please indicate the total direct and indirect costs, including capital costs, or reusing or recirculating water in cents per thousand gallons. An example of costs associated with reuse would be cooling towers for the purpose of allowing cooling water to be recirculated several times).

19. Total cost of water disposal (including waste treatment) $_____
Please indicate the total direct and indirect costs of water disposal (including any waste treatment) in cents per thousand gallons.

20. Total cost of obtaining water, treatment prior to use, reuse treatment, and disposal of water $_______.
(Please indicate the total cost of these four categories in cents per thousand gallons.)

NOTE: The answer to Question 20 should be the sum of the answers given for Questions 16, 17, 18, and 19.

EXHIBIT 5-3

Descriptive Statistics
of Sample of Industrial Water Users

Variable	Derived From Question Number	Mean
EMPLOY	3	501.57
AVDPROD	5	938.71
AGEPE	8	10.86
IW (000)	9	11,390.36
ACIW (¢/000)	9,16	12.63
TCI ($)	16	1,299.19
GWIWRAT	9,13	8.75
COOLPER	13,14	.58
GW (000)	13	59,573.28

Source: Responses to questionnaire (Exhibit 5-2) telephone calls had a much lower usable response rate than did visited firms, i.e., 20 percent.

The Sample

The purpose of obtaining a sample from a particular population is to make statistical inferences about the population as a whole. To test for randomness in the sampling procedure, t-tests were performed on all of the variables. Because population means were not available, it was necessary to employ a pooled two sample t-test where the means of two pooled samples were compared. Past statistical studies indicated that respondents who sent in their questionnaire late were similar to nonrespondents. Thus the total sample of responses was broken into an "on time" pool and a "late" pool, where late respondents were defined as those receiving more than two follow-up calls.[6] If the t-test statistics were statistically significant, it would indicate that response bias was introduced and the sampling procedure could not be considered a random process. The pooled two sample t-test is given by:

$$t = m_1 - m_2/\hat{\sigma}^2 \sqrt{N_1 \cdot N_2/n_1 + n_2}$$

where

$$\hat{\sigma}^2 = n_1 S_1{}^2 + n_2 S_2{}^2 + n_2 S_2{}^2/n_1 + n_2 - 2$$

The SAS t-test procedure uses Satterthwaite's approximation to compute the degrees of freedom associated with the t approximation.[7]

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[6] A.N. Oppenheim, Questionnaire Design and Attitude Measurement, New York: Basic Books, Inc., (1966) p. 34.

[7] F.E. Satterthwaite, "An Approximate Distribution of Estimates of Variance Components," Biometrics Bulletin, (1946), pp. 113-114.

Satterthwaite's approximation is given by:

$$\hat{r}_s = \{[MS_1/r_1 + 1)] + [MS_2/(r_2 + 1)]\}^2$$

$$\frac{[MS_1/(r_1 + 1)]^2 \quad + \quad [MS_2/r_2 +1)]^2}{r_1 \qquad\qquad\qquad r_2}$$

where

$\hat{r}_s$ = Satterthwaite's degrees of freedom approximation

MS = mean square

r = degrees of freedom for each respective sample tool

The test for randomness hypothesizes that the means of the two sample pools are not significantly different. Exhibit 5.4 shows that the results of the t-test comparisons for all variables between late and early respondents were all statistically insignificant at .10 level. Since all the respondents and non-respondents are thought to have similar characteristics, a lack of significance between early and late respondent indicates randomness and inferences about the population can be made from the sample.

The Jackknife Procedure

Because of the small number of observations in this study, it was necessary to employ the jackknife statistical procedure which is designed to eliminate small sample bias by improving the robustness of a beta coefficient least squares estimator.[8] An improvement in robustness refers to smaller and smaller departures from normality. The jackknife procedure is outlined below:

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[8] Rupert G. Miller, "The Jackknife - A Review," Biometrika, (1974), 61, p. 6.

(1) Estimate the appropriate regression coefficients based on the entire sample size, n = 14; where $\hat{\beta}$ is the least squares estimator $(X'X)^{-1}X'Y$.

(2) The jackknife is then applied by successively deleting each row of X and Y. That is, estimate regresion coefficients by leaving out the i'th observation $(\hat{\beta}-i)$.

(3) Pseudo-values of β are then computed by $\tilde{\beta}_i = n\hat{\beta} - (n - 1)\,\hat{\beta}-1$ where 1, 2, 3. . . , 14.

$\tilde{\beta}_i$ = each pseudo-value.

(4) The jackknifed beta estimate is computed by the mean of the pseudo-values where

$$\beta_J = \frac{\sum_{i=1}^{14} \tilde{\beta}_i}{14}$$

The jackknife is employed for the estimates of both the total cost and intake water regression equations in order to improve the robustness of the regression estimates.

CHAPTER VI

ESTIMATED INDUSTRIAL WATER DEMAND SCHEDULES

The purpose of this chapter is to use the data collected from the questionnaires to estimate total cost functions for intake water and then water demand functions. The SAS stepwise regression procedure is employed to search for the best cost and demand functions. The final equation variables are chosen on the basis of their relative contribution to R^2, i.e., variables which do not pass the 0.05 stepwise F-test are not retained in the model.

Estimation of Intake Water Demand Function

In order to estimate the intake water demand function it is first necessary to estimate a total cost function from which the average cost of intake water (price) can be derived. The general equational form was specified in equation (5-3); the specific form is based on arguments developed in the previous chapters and is:

$$TCI = b_0 + b_1EMPIW + b_2IW^2 + b_3DTIW + b_4APIW + b_5DTEKIW \qquad (6-1)$$

Using the SAS stepwise procedure (Exhibit 6-1) generates the following estimate of the total cost of intake water:

$$\begin{aligned} TCI=&317.04 + .0001IW^2 \\ &(2.33) \qquad (4.48) \\ R^2 &= 0.94 \qquad F = 94.68 \qquad (6-2) \end{aligned}$$

The values in parentheses are t-statistics which indicate statistical significance at the 0.05 level. The overall model is also significant at the 0.0001 level.

Using equation (6-2) to estimate the average cost of intake water (ACIW), the following intake water demand function is estimated:

EXHIBIT 6-1

Total Cost Function Stepwise Search
Regression Procedure for Dependent Variable TCI

R Square = .94

	Included Variables Entered	DF	F	Prob > F
Step 1	Regression	1	202.83	.0001
	Error	12		
	Total	13		
		B Value		
	Intercept	31,704		
	SQIW or IW^2	.0002	202.83	.0001

R Square = .95

	Variable EMPIW Entered	DF	F	Prob > F
Step 2	Regression	2	110.49	.0001
	Error	11		
	Total	13		
		B Value		
	Intercept	33,642		
	SQIW or IW^2	.0003	12.73	.004
	EMPIW	-.004	1.96	.19

R Square = .94

	Variable EMPIW Removed	DF	F	Prob > F
Step 3	Regression	1	202.83	.0001
	Error	12		
	Total	13		
		B Value		
	Intercept	31,704		
	SQIW or IW^2	.0002	202.83	.0001

No other variables met the .50 significance level for entry into the model.

$$IW = 10^{\beta_o} \cdot e^{\beta_1 ACIW} \cdot EMPLOY^{\beta_2} \cdot AVDPROD^{\beta_3} \cdot COOLPER^{\beta_4} \cdot GWIRAT^{\beta_5} \qquad (6\text{-}3)$$

This equational form was selected over the more traditional linear models since it allows for the more realistic situation where the value of the price elasticity varies directly with price. By using logarithmic transformation of the intake water equations it is possible to multiply the beta coefficient for price times the value of price in order to obtain the price elasticities of demand.

The stepwise regresion procedure is used again to estimate the intake water demand function. The stepwise procedure requires a partial F-statistic with a 0.05 level of significance in order for a variable to be added to the model and a 0.05 level of significance to avoid deletion. The procedure generates the following results:

Intake Water Demand Model

$R^2 = .76$

Parameter	F-Value	Prob > F
Overall model	10.61	.002

Parameter	B Estimate	T for Ho: Parameter = 0	PR > T
Intercept	5.38	9.65	.0001
ACIW	- .078	-2.28	.04
DTECHO	-2.62	-3.22	.009
DTYPE	-1.57	-3.98	.002

These results show that all independent variables are significant at the .05 level. The overall model is significant at the .0001 level with an R^2 of .76. The stepwise procedure used to generate these results is shown in Exhibit 6-2.

EXHIBIT 6-2

Intake Water Demand Equation With ACIW As Price
Stepwise Regression Procedure For Dependent Variable LIW

R Square = .51

	Variable DTYPE Entered	DF	F	Prob > F
Step 1	Regression	2	5.79	.02
	Error	11		
	Total	13		
		B Value		
	Intercept	4.74		
	ACIW	- .03	.54	.47
	DTYPE	-1.79	11.47	.006

R Square = .76

	Variable DTECHO Entered	DF	F	Prob > F
Step 2	Regression	3	10.6	.002
	Error	10		
	Total	13		
		B Value		
	Intercept	5.38		
	ACIW	- .078	5.21	.04
	DTECHO	-2.62	10.37	.009
	DTYPE	-1.57	15.81	.002

No other variables met the .50 significance level for entry into the model.

In order to estimate the intake water demand equations it is necessary to jackknife each of the beta coefficients as shown in Exhibits 6-3 through 6-5. The significance of the technology (DTECHO) and plant type (DTYPE) variables generates four different intake water demand equations due to the fact that a dummy variable effectively serves as a "demand shifter," i.e., its use results in two separate but parallel intake water demand functions. When a dummy variable is equal to zero, the equation constant is equal to ten to the power of the intercept beta coefficient. When it is equal to one, the value of the equation constant is ten to the power of the intercept beta coefficient plus or minus the beta coefficient of the dummy variable. Consequently, the fact that the DTECHO and DTYPE variables are statistically significant means the following four intake demand functions can be estimated:

$$IW = 10^{5.41} \cdot e^{-.078 \cdot ACIW} \tag{6-3}$$

when DTECHO = 0 (below average technology)

DTYPE = 0 (paper plant)

$$IW = 10^{5.41-2.51} \cdot e^{-.078 \cdot ACIW} \tag{6-4}$$

when DTECHO = 1 (average or advanced technology)

DTYPE = 0

$$IW = 10^{5.41-1.57} \cdot e^{-.078 \cdot ACIW} \tag{6-5}$$

when DTECHO = 0

DTYPE = 1 (chemical plant)

$$IW = 10^{5.41-1.57-2.51} \cdot e^{-.078 \cdot ACIW} \tag{6-6}$$

when DTECHO = 0

DTYPE = 1

EXHIBIT 6-3

Intercept
Jackknife Beta Estimate

Obs.		$\hat{\beta} = 5.39$			
w/o 1	75.46	-	(5.38)(13)	=	5.52
w/o 2	75.46	-	(5.38)(13)	=	5.91
w/o 3	75.46	-	(5.39)(13)	=	5.39
w/o 4	75.46	-	(5.31)(13)	=	6.43
w/o 5	75.46	-	(5.41)(13)	=	5.13
w/o 6	75.46	-	(5.38)(13)	=	5.52
w/o 7	75.46	-	(5.52)(13)	=	4.00
w/o 8	75.46	-	(5.63)(13)	=	2.27
w/o 9	75.46	-	(5.36)(13)	=	5.78
w/o 10	75.46	-	(5.39)(13)	=	5.39
w/o 11	75.46	-	(5.39)(13)	=	5.39
w/o 12	75.46	-	(4.79)(13)	=	13.19
w/o 13	75.46	-	(5.42)(13)	=	5.00
w/o 14	75.46	-	(5.74)(13)	=	.84

$\hat{\beta}_J = 75.76/14 = 5.41 =$ Jackknifed beta coefficient for Intercept

EXHIBIT 6-4

ACIW
Jackknife Beta Estimate

Obs. #			$\hat{\beta} = -.078$		
w/o 1	-1.09	-	(-.074)(13)	=	-.128
w/o 2	-1.09	-	(-.076)(13)	=	-.09
w/o 3	-1.09	-	(-.078)(13)	=	-.08
w/o 4	-1.09	-	(-.077)(13)	=	-.09
w/o 5	-1.09	-	(-.077)(13)	=	-.09
w/o 6	-1.09	-	(-.078)(13)	=	-.08
w/o 7	-1.09	-	(-.088)(13)	=	.05
w/o 8	-1.09	-	(-.096)(13)	=	.16
w/o 9	-1.09	-	(-.076)(13)	=	-.10
w/o 10	-1.09	-	(-.078)(13)	=	-.08
w/o 11	-1.09	-	(-.078)(13)	=	-.08
w/o 12	-1.09	-	(-.034)(13)	=	-.65
w/o 13	-1.09	-	(-.080)(13)	=	-.05
w/o 14	-1.09	-	(-.100)(13)	=	.21
					-1.098

$\hat{\beta}_J = -1.098/14 = -.078 =$ Jackknifed beta coefficient for ACIW

EXHIBIT 6-5

DTECHO
Jackknife Beta
Estimates Intake Water Demand

Obs. #		$\hat{\beta} = -2.62$			
w/o 1	-36.68	-	(-2.58)(13)	=	-3.14
w/o 2	-36.68	-	(-2.61)(13)	=	-2.75
w/o 3	-36.68	-	(-2.62)(13)	=	-2.62
w/o 4	-36.68	-	(-2.61)(13)	=	-2.75
w/o 5	-36.68	-	(-2.61)(13)	=	-2.75
w/o 6	-36.68	-	(-2.61)(13)	=	-2.75
w/o 7	-36.68	-	(-2.65)(13)	=	-2.23
w/o 8	-36.68	-	(-2.64)(13)	=	-2.36
w/o 9	-36.68	-	(-2.55)(13)	=	-3.53
w/o 10	-36.68	-	(-2.57)(13)	=	-3.27
w/o 11	-36.68	-	(-2.62)(13)	=	-2.62
w/o 12	-36.68	-	(-2.46)(13)	=	-4.70
w/o 13	-36.68	-	(-2.67)(13)	=	-1.97
w/o 14	-36.68	-	(-2.99)(13)	=	2.19
					-35.25

$\hat{\beta}_J = -35.25/14 = -2.51 =$ Jackknifed beta coefficient for DTECHO

The estimated cost and demand functions were checked for possible multicollinearity. The stepwise procedure for the TCI function indicated two significant variables as shown in Exhibit 6-1. However, the addition of EMPIW to SQIW in the TCI function substantially changed the regression coefficients and did not significantly add to R^2. Because a check of the TCI correlation matrix showed EMPIW highly correlated with SQIW, it was eliminated from the TCI function. In addition, a check for high correlation between independent variables in the final intake demand equation showed no evidence of multicollinearity. The correlation matrix revealed that none of the independent variables included in equations (6-3) through (6-6) were variables highly correlated.

The estimated regression models were also checked for appropriateness. A regression model is assumed to have independent normal random variables with mean zero and constant variance. If the model is appropriate, observed residuals should reflect these properties. To check for model aptness, scatter diagrams of the residuals in each model were plotted. In each case, the scatter diagrams displayed no systematic tendencies to be positive or negative. Absence of systematic variation in the residual scatter plots constitutes evidence which suggested that the assumed models were appropriate.

Another assumption of OLS regressions is that of constant variance among error terms. One way to test for unequal variance is to calculate a rank correlation between the absolute value of the residual (RABS) and the value of the independent variable. Relatively high coefficients of correlation would indicate a systematic departure from constant variance, i.e., heteroscedasticity. The results of the rank correlation test are shown in Exhibit 6-6. The test shows no significant level of correlation between RABS and each of the independent variables. The combination of evidence from the scatter diagrams and the rank correlation test allow the assumption of model appropriateness. Each of the model equations meet the assumption of OLS without the need for model transformation.

Interpretation and Results

The negative sign of the DTECHO variable indicates that intake water varies inversely with technological improvements. The behavior of the DTECHO variable confirms the expectation that the proportion of intake water used by a firm tends to decrease as overall technological improvements occur, ceteris paribus. The relationship between DTECHO and the quantity of intake water reinforces the findings of the 1974 NBER study which attributed a negative relationship between overall technological improvements and intake water to evidence which showed that improvements in technological processes tend to translate into more efficient usage of intake water. As expected the DTYPE variable also displays a negative sign which indicates that the type of plant (either paper or chemical) has a significant effect on the quantity of intake water demanded. The data reveals that Arkansas paper plants demand more intake water than their chemical plant counterparts.

The fact that the better coefficient of ACIW has a negative sign confirms the hypothesis that price and quantity of intake water are inversely related. The negative sign can be interpreted to mean that heavy water-using firms respond to increases in the price of intake water by reducing the quantity of intake water. This result confirms

EXHIBIT 6-6

Rank Correlation Coefficients

	Total Cost Equation		
	RABS	TCI	SQIW
RABS	1.00	-.16	.05

	Intake Water Demand Equation				
	RABS	LIW	ACIW	DTECHO	DTYPE
RABS	1.00	-.24	.45	-.44	.46

(NOTE: RABS is the absolute value of the residuals.)

the findings of Bramer and Motz, DeRooy, and Leone, Ginn and Lin. These authors found that firms respond to price increases by reducing the quantity of intake water demanded. In each case, they found a price inelastic demand for intake water.

Price Elasticity of Demand

Equations (6-3) through (6-6) can be used to generate separate demand curves for the paper and chemical industries and for different levels of technology. The average cost of intake water (ACIW) is the only variable necessary to construct the demand curves. From a statistical viewpoint it is not wise to extrapolate the estimated relationships for prices (ACIW) outside the range for which the demand functions were estimated, which, in this sample, ranged from 0.9¢/1,000 gallons to 21.7¢/1,000 gallons with an average of 12.6¢/1,000 gallons. Prices paid by paper plants ranged from 10.0 to 21.7¢/1,000 gallons with an average 13.6¢/1,000 gallons. The corresponding prices for chemical plants were 0.9 to 21.0¢ with n average of 12.1¢. These figures can be used in equations (6-3) through (6-6) to construct the demand functions for intake water. For example, using the equation (6-3) and assuming price is equal to 10.0¢/1,000 gallons, the estimated quantity of intake water demanded by a paper mill with average or advanced technology would be equal to $10^{5.41}$ times $e^{-0.78.10.0¢}$ or 36.4 million gallons per day. Other points in the demand function for paper plants with average or advanced technology would be derived by inserting other values for ACIW into equation (6-3). The demand function for paper plants using below average technology would be derived in a similar manner using equation (6-4). The demand function for chemical plants would be derived by inserting various prices ranging from 0.9¢ to 21.0¢/1,000 gallons into equation (6-5) for plants using average or advanced technology and (6-6) for plants using below average technology.

It is sometimes useful to know how plants would respond to increases in the cost of intake water due to, perhaps, more expensive drilling costs, more stringent water quality standards, or other public policies. The price elasticity of demand measures this responsiveness as the ratio of the percentage change in quantity of intake water demanded to the percentage change in price. If the absolute value of this ratio exceeds one the demand for intake water is said to be elastic, i.e., responsive, to price changes; if it is less than one, inelastic or not responsive; and if it is equal to one, demand is said to be unit elastic.

As indicated earlier in this chapter the exponential form of the estimated demand function permits elasticity to vary with respect to different prices, i.e., as price increases so too does the absolute value of the elasticity coefficient. Exhibit 6-7 shows the estimated elasticities at different prices for both chemical and paper plants with different levels of technology. The results indicate that the price elasticity of demand for intake water is slightly elastic at the average price paid by paper plants (13.6¢) and slightly inelastic at the average price paid by chemical plants (12.1¢). It should be remembered that these estimates were developed from cross section data. The use of time series data would probably reveal a more elastic demand schedule as firms have more time to adjust their production process to higher water costs.

EXHIBIT 6-7

Price Elasticities of Demand for the Paper and Chemical Industries

Price (ACIW) ¢/1,000 gal.	Elasticity
1	-0.07
2	-0.15
3	-0.22
4	-0.30
5	-0.38
6	-0.46
7	-0.54
8	-0.62
9	-0.70
10	-0.78
11	-0.85
12	-0.93
13	-1.01
14	-1.09
15	-1.17
16	-1.25
17	-1.33
18	-1.41
19	-1.48
20	-1.56
21	-1.64
22	-1.72

Source: Derived from equations (6-3) through (6-6)

Knowledge of the price elasticities of demand can be very useful in helping to determine the effects of various public policies on the withdrawal of water for industrial purposes. Water is a scarce good and, like other scarce goods, is rationed to users in a variety of ways. If purchased from a central system it is rationed by price in periods of normal availability and by various rules during periods of water shortages. If it is pumped from underground and surface sources its price is the cost of acquisition, treatment, and disposal, but this cost is too low to ration the water efficiently since it does not reflect the opportunity cost to the rest of society (see Chapter IV, pages 41-42 for a further elaboration of this point). It is not surprising, therefore, that there are areas throughout the country, including parts of Arkansas, that are facing serious problems of water shortages, particularly groundwater depletion. From an economic standpoint each user has an incentive to use water to the point where its cost equals its marginal revenue product or contribution to total revenue. Since the cost of water is very low, large quantities of water are used in the production process. This situation may be economically efficient for the water user but it is not efficient from the standpoint of society as a whole. One of a number of possible solutions is to increase the cost of self-supplied waters to its users, perhaps through a surcharge or licensing system. While it might be difficult to estimate the surcharge which would reflect accurately the opportunity cost of self-supplied water the price elasticity of demand estimated in this study could be used to estimate the effect on intake water demand of various surcharges. For example, if the current average cost of intake water to a chemical firm was

13.0¢/1,000 gallons and ten percent surcharge was imposed on all self-supplied intake water, the quantity of intake water would be expected to decrease by approximately ten percent, ceteris paribus. Of course, the precise impact of this ten percent surcharge may vary from this estimate because of unavoidable statistical errors in the estimate as well as changes in the factors and assumptions on which the estimates were made. As indicated earlier, the longer the time period under consideration the more elastic the demand is likely to be and the more pronounced effect of a given surcharge on intake water demand. Also, the nature of the production process is likely to change over time and the relationship between price and intake water demand may also change. It is likely that the cost of acquiring intake water will increase in the future and with that increase will come new, as yet unestimated, relationships between price and quantity demanded. These factors, some of which are admittedly hard to quantify, must be taken into account in estimating the effect of the surcharge policy. In making these estimates it would be useful to consult individuals who are familiar with the production process in each of the affected industries and know the capacities and limitations of the use of water in these processes.

Limitations of the Study

One of the implicit objectives of this study was to develop water demand functions which could be used to estimate future water demands. The estimated demand functions, however, are subject to limitations which preclude their use in forecasting. Perhaps most basic is the lack of a statistically significant measure of output or employment which is necessary as a basis to forecast. As output changes so too will the demand for water, independent of what happens to price; however, statistically reliable estimates of the coefficients relating output to water use could not be estimated from the available data. Data limitations also meant the absense of information on the prices of nonwater inputs in the production process. This implies that input prices are fixed which may be an accurate assumption in the short run but not in the long run when changes in relative input prices are likely to affect the use of intake water.

Another limitation, not only to the use of these demand function for forecasting purposes but also to their use in assesssing the impacts of various public policies, is the relatively small size of the sample. Although statistical procedures were employed to deal with small samples, there is the possibility that a larger sample would have yielded estimates which were more accurate of the true population and significantly different. The failure to obtain a larger sample was a major disappointment especially in light of the tediously planned efforts to obtain a large response. Under the existing laws and regulations protecting the autonomy of businesses, there does not appear to be a efficient way to obtain the information necessary to undertake a study of this kind.

Finally, it should be understood that the estimated demand functions are not meant to be used to predict the demand of individual plants. The aggregate nature of the models makes the determination of individual demands subject to a high degree of error.

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