Environment Canada
Environnement Canada
Environmental Conservation
Conservation de l'environnement

INDUSTRIAL WATER DEMAND IN BRITISH COLUMBIA

Prepared by
Steven Renzetti

February 1986

Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

ENVIRONMENT CANADA
ENVIRONMENTAL CONSERVATION SERVICE

INDUSTRIAL WATER DEMAND IN BRITISH COLUMBIA

PREPARED BY

STEVEN RENZETTI

INLAND WATERS DIRECTORATE
PACIFIC AND YUKON REGION
VANCOUVER, B.C.

FEBRUARY 1986

ABSTRACT

This paper reports the results of an econometric study of the water intake demands and water valuation for British Columbia industries. The data set employed is the 1981 National Industrial Water Use Survey. Little research has been conducted in this field and, thus, the report discusses methodology at some length.

Water use costs constitute a very small part of the total costs of British Columbia firms. Water's cost share ranges from 0.5 percent (Metal Fabricating) to 3.0 percent (Wood Products). Despite the relative insignificance of the cost of water, almost all industries' water demands are found to be price sensitive. Single equation intake demand functions are estimated with the prices of water intake, treatment, recirculation and discharge and the level of output as explanatory variables. The water intake own price elasticities range from -0.01 (Primary Metals) to -1.7 (Petroleum) and output elasticities vary from 0.14 (Mineral Products) to 1.9 (Primary Metals). Thus, industrial water demands are strongly influenced by water intake costs and the level of firm output.

There have been few previous studies which have investigated the value of water to industrial users in Canada. Such information will be important for achieving maximum benefits from water use as demands for water increase in the future. This study investigates industrial water

valuation by British Columbia manufacturing firms and estimates willingness to pay figures. Average gross willingness to pay varies from \$9 per 1000m^3 (1981 dollars) for Paper and Allied Products to \$2583 per 1000m^3 for Food and Beverage industries while average net willingness to pay ranges from \$0.9 per 1000m^3 for Primary Metals to \$48 per 1000m^3 for Food and Beverage products.

The empirical results of this study must be viewed as being preliminary. More sophisticated econometric techniques are feasible which should result in more reliable estimates of industrial water demand. Most importantly, the demand for water should be seen as one of many, interrelated, demands the firm expresses. This suggests that the demand for water should be statistically estimated as one of a set of interrelated demand equations for each industry.

RESUME

Ce rapport présente les résultats d'un étude économétrique des requêtes de prise d'eau et d'estimation de la valeur d'eau pour les industries de la Colombia-Britannique. La source des données utilisée dans ce rapport est le "relevé d'utilisation d'eau industrielle nationale de 1981". Le rapport aussi discute en detail la méthodologie employée vue que très peu de recherche se fait dans ce domaine.

Les coûts d'utilisation d'eau sont minimes compare aux frais total de fonctionnement des industries en Colombie-Britannique et le coût de partage pour l'eau varie de 0.5% (fabrication de produit en métal) à 3.0% (industrie de bois). Malgré ce coût insignificatif de l'eau, la demande d'eau reste sensible au prix pour presque toutes les industries. La prise d'eau pour plusieurs demandes fut estimée par une seule équation comprenant de variables (indépendentes) de coût de prise d'eau, de traitement, de recirculation, d'évacuation d'eau et du niveau de production. Les indices d'élasticitées de ces coûts de prise d'eau varient de -0.01 (métaux principaux) à -1.7 (produit de pétrole) et celles de productions furent de 0.14 (prodiut minéaux et non métalliques) à 1.9 (métaux principaux). Ainsi la demand d'eau par les industries est fortement influencée par les coûts de prise d'eau et de niveau de production.

La valeur économique d'eau pour les industries est une question qui n'a pas été poursuivie au Canada mais qui par contre est d'une importance critique pour la distribution efficace d'eau entre les divers usagers. La valeur industrielle d'eau pour les industries en Colombie-Britannique fut examinée en estimant les donnés sur la volonté du consommateur pour payer pour cette ressource. La moyenne brute la volonté pour payer fut de $9 par 1000 m^3 (en dollard de 1981) pour l'industrie de papier à $2583 par 1000 m^3 pour l'industrie des aliments et boissons. Par contre la moyenne net fut de $0.9 par 1000 m^3 pour les métaux principaux à $48 par 1000 m^3 pour l'industrie des aliments et boissons.

Les résultats empiriques de cette étude sont necessairement preliminaires. Des techniques économétriques plus avancées sont réalisables et sont planifiés prochainement. De prime abord la demande d'eau doit être vue comme une des nombreuses demandes reliées que l'industrie desire. Par consequence, la demande d'eau doit être estimé d'une façon statistique et comme une des variables reliées dans l'équation de demande en eau pour chaque industrie.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

CHAPTER I

INTRODUCTION

Canada is endowed with an enormous quantity of freshwater resources. This situation has, until very recently, led to the perception that freshwater is not a scarce resource. As a result little economic analysis has been conducted into the structure of Canadian water demands. What work has been done has concentrated on examining the price sensitivity of urban domestic water demands. The nature of industrial water demands in Canada has been essentially ignored.

This situation is changing. It is now widely agreed that freshwater can no longer be treated as a 'free good'. Therefore, an understanding of all sectors' water demands is required in order to manage this resource optimally. This project examines the nature and structure of the British Columbia manufacturing and mining industries' demands for water. Some of the questions which will be addressed herein include the following:

1. Are industrial water demands sensitive to changes in price and, if so, to what degree?
2. How do British Columbia industries differ in the degree of price sensitivity of their water demands?
3. What is the relationship between water intake and other forms of industrial water use (e.g. recirculation and treatment)?
4. What value do industries place on their water use?

These questions (and others) will be addressed through the use of statistical models of water demands. Some of the economic and statistical concepts used here are complex and explanations have been provided where they appeared necessary.

The data set used in the statistical portions of this report comes from the 1981 Industrial Water Use Survey conducted by Environment Canada. While the survey was national in scope this study restricts its attention to British Columbia manufacturing industries. The manufacturing industry is an important water user in British Columbia. According to the 1981-1982 Canada Water Year Book, the manufacturing sector was responsible for water withdrawals of 5600 million litres per day while the total recorded withdrawals for the province were 9301 million litres per day. Thus, the manufacturing sector accounted for 61 percent of all recorded water withdrawals in British Columbia.

Two things should be emphasized before proceeding. First, the results reported here are preliminary. Because there has not been very much work done in this field, there still exist disputes regarding methodology and interpretation of results. Second, this report's purpose is to summarize this project's methods and empirical results (and tentative conclusions) to date. Related topics which could be explored in the future include the use of statistical water demand equations in forecasting, the use of industrial valuation of water estimates in river basin planning models and the use of economically and statistically more sophisticated models of industrial water demands.

CHAPTER II

BACKGROUND

A. Introduction

The purpose of this chapter is to examine some of the background issues which surround the estimation of industrial water demands in British Columbia. These background issues may be grouped into two broad categories. First, past research relating to the modeling, measurement and estimation of water demands is reviewed. Second, the institutional framework in which the three levels of government regulate water use in British Columbia is discussed.

It should be noted that the following is not meant to be an exhaustive review of the relevant literature. For a comprehensive discussion of applied water demand analysis the reader is referred to the volume edited by Kindler and Russell (1984). The jurisdictional division of powers over water use regulation is reviewed in Ruggeberg and Thompson (1985).

B. Past Research on Water Demands

The economic analysis of water demands has only recently received much attention. Relative to other fields of applied economic research, this area of research is still in its infancy. Several factors have inhibited economic research in this field. The popular perception of the relative abundance of water and the prevailing reliance on supply management (i.e. where an imbalance between demand and supply for water has existed the perceived problem was how to increase supply at the least cost) have certainly stifled concern with regulating water use. These attitudes have interferred with the gathering of data necessary to do demand studies. In addition, the frequent absence of a discernible market for water and associated price for water have made modeling water demands difficult. Despite these difficulties water demands have been studied in several sectors. Most of the existing research has concentrated on municipal-domestic water demands. The major concerns addressed in this literature are discussed later in this chapter. Very little research has been directed at industrial water demands. This literature is examined in some detail. Finally, the least studied issue involves the valuation of industrial water use. A detailed discussion of this topic is delayed until Chapter 7.

There have only been a few economic studies of water's role in the production process. For the most part these studies have concentrated on estimating the price elasticity of intake water demand and the elasticities of substitution between water and other inputs. These studies have considered either a single industry, using a small sample of firm-level input data or the entire manufacturing industry using highly aggregated input data.

DeRooy (1974) represents one of the earliest attempts to examine statistically industrial water demands. The data set consists of water cost and use data from a cross section of 30 New Jersey chemical firms. Single equation demand functions are separately estimated for water use in cooling, processing and steam production. Explanatory variables in each equation include firm output, the price of water intake (proxied by the average cost of water use) and a technology dummy variable related to the plant's age. Estimated price elasticities range from -0.354 (processing) to -0.894 (cooling). No attempt to include water recirculation or other inputs or to estimate the demand equations as a system is made.

Greberstein and Field (1979) estimate a translog cost function for the U.S. manufacturing industry and include water as an input to production. The cross-sectional data set consists of fifty state level observations on input prices (the price of intake water was proxied by its average cost). The study finds intake water's estimated cost share to be 1.2 percent and finds an own price elasticity of -0.326. The study also finds water-labour substitutibility and water-capital complementarity. In a related study, Babin, Willis and Allen (1982) use a more dissaggregated data set in order to estimate translog cost functions for U.S. two-digit Standard Industrial Classification (SIC) code manufacturing industries. The study employs cross-sectional state level data on input prices for 1973 (again, intake water's price is proxied by its average cost) and imposes constant returns to scale in its estimation model. The water cost share ranges from 0.21 percent (Fabricated Metals) to 7.9% (Chemicals) and price elasticities range from being insignificantly different from zero (Food, Machinery, Electric and

Electronic Products) to -0.66 (Paper and Allied Products). The study finds water-capital complementarity in Paper, Metal Fabricating, Minerals and on a pooled regression of all Manufacturing while it finds water-capital substitutibility in Food and Electrical Equipment. Both of these studies use an iterative Zellner estimation procedure and assume that the public utility supplied average costs of water use accurately reflect the shadow price of water for self-supplied firms.

Only one study to date confronts the problem of defining the price of water for self-supplied firms. Ziegler and Bell (1984) use a cross-sectional data set of 23 "high volume water using firms" in Arkansas paper and chemicals industries which gives total cost of intake water use, age of the plant and a description of the production process in use. Ziegler and Bell then conduct a two-part estimation procedure. First, total intake expenditure is regressed against the square of water intake. This allows the computation of the average and marginal costs of water intake.[1] These then are both used in separate single equation water intake demand functions. These demand functions are estimated in loglinear form and have the intake price (proxied by either average or marginal cost) and technology dummies as explanatory variables. Firm output is not included as an explanatory variable. Despite the problem associated with the overly simplified estimation model, Ziegler and Bell conclude that average cost acts as a better proxy for the price of intake water.

---

1 See Chapter IV for a detailed discussion of this procedure.

A study by Sims (1979) is only indirectly related to industrial water demand modeling but is discussed here as it is the only published research into industrial water demands using a Canadian data set. Sims applies a translog cost function to the estimation of the pollution abatement responsiveness of plants in the brewing industry in Canada. The study finds a high degree of responsiveness to sewer charges (price elasticity of water discharge was estimated at -0.443). However, due to the structure of the sewer charges (the amount charged being a function of the quantity of water discharged and the concentration of wastes in discharge water) a positive relationship between intake water and sewer charges is found. The Sims research does not integrate the estimation of water demand equations into a more general econometric model of the firms' production processes.

These production studies have several common features. They attempt to incorporate water use into an economic model of firm decision making. They address the empirical question of whether industrial water intake is price responsive and, importantly, they all reject the null hypothesis that water intake demands are not sensitive to the price (or average cost) of intake water.

Another important part of the water demand literature concerns itself with the estimation of municipal residential water demands. In contrast to the production studies reviewed above the municipal water demand studies typically draw on data sets with large numbers of observations and pay considerable attention to the 'correct' definition of the price of water. Interested readers should consult Kindler and Russell (1984, Chapter 2) which surveys the municipal water demand literature.

Table 2.1 summarizes the major findings of recent municipal water demand studies. All of these works find residential water use to be sensitive to price (price elasticities ranging from -0.115 to -1.12) and to income (income elasticities ranging from 0.11 to 2.14). While a variety of functional forms and data sources were used in these studies, their findings would indicate that price sensitive residential water demands are the norm rather than the exception.

With the exception of the definition of the price of water most residential water demand studies have used fairly similar models and methods. The demand for water is typically modeled to be a function of the following explanatory variables: price, household income, the number of residents in the household and some variable measuring atmospheric conditions (centimetres of rainfall per year, mean daily temperature, etc). Examples of other explanatory variables which have been included are: residential lot size, number of bathrooms per household, type of residence and education level of residents in the household.

Most of the water demand functions are estimated as single equations. In this case, economic theory provides little guidance

TABLE 2.1

Summary of Recent Municipal Water Demand Studies [1]

Author	Region Studied	Price Elasticity[2]	Income Elasticity
Andrews and Gibbs (1975)	Miami	-0.51 to -0.62	0.52 to 0.81
Grima (1972)	Ontario	-0.75 to -1.07	0.48 to 0.56
Howe and Linaweaver (1967)	United States	-0.231 to -1.12	0.319 to 0.662
Foster and Beattie (1979)	United States	-0.33 to -0.68	0.18 to 0.37
Sewell and Roueche (1974)	Victoria	-0.457	0.268
Billings (1982)	Tucson	-0.56 to -0.66	2.14
Sigurdson (1982)	Saskatchewan and Manitoba	-0.815	not reported
Hanke and de Mari (1982)	Malmo, Sweden	-0.15	0.11
Al-Qunaibet and Johnston (1985)	Kuwait	-0.771 to -0.957	0.06 to 0.211

NOTES:

1. A more complete summary of recent studies can be found in Al-Qunaibet and Johnston (1985)

2. The price elasticity of water demand is defined as the percentage change in the quantity of water demanded in response to a one percent change in the price of water. Thus, a value of -.50 would indicate a one-half of a percent decline in quantity demanded in response to a one percent increase in price. The income elasticity is defined as the percentage change in the quantity of water demanded when the consumer's income increases by one percent.

to the 'proper' functional form to be estimated. As a result, most studies estimate and report several functional forms (log-linear, double log, linear, Stone-Geary, etc). Most studies use an ordinary least squares estimation procedure (with the exception of recent instrumental variables attempt - cf. Jones and Morris, 1984).

An important way in which empirical studies of residential water demands differ is the manner in which price is defined. These different definitions represent researchers' attempts to deal with the potential simultaneity bias when estimating demand equations in the face of block rate price structures.

In the case of block rate pricing, the price paid for the marginal unit is determined by the total quantity of water consumed. Attempting to estimate a demand function for water under the false assumption of price exogeneity may, then, lead to a simultaneity problem and yield biased parameter estimates (cf. Kmenta, 1971; Maddala, 1977). This is because both the left hand side variable (the quantity of water demanded) and at least one right hand side variable (the price of water) are ultimately functions of the quantity of water. As a result both variables are determined simultaneously and it is very difficult to use one to explain the variations in the other. Thus, the price variable's estimated coefficient may be biased, (that is, the expected (or average) value of the coefficient cannot be assumed to equal the true, unknown population mean value of the coefficient) because the simultaneity problem leads the price variable to be correlated with the error term and this violates one of the basic assumptions underlying Ordinary Least Squares (OLS) estimation.

The existence of this problem has been recognized for some time but has been acted upon only recently. The following discussion considers three approaches to the simultaneity problem in the estimation of residential water demands.

The first approach ignores the simultaneity problem. This method uses average cost of water (total water intake expenditures divided by gross water intake) as a proxy for the marginal price of water (DeRooy, 1974; Foster and Beattie, 1979; Grebenstein and Field, 1979; Babin, Willis and Allen, 1982; Stone and Whittington, 1984). This method has been adopted either because of data limitations or because of an <u>a priori</u> belief that the simultaneity estimation error is in some sense relatively small (cf. Foster and Beattie, 1981). There are two shortcomings to this approach. The obvious flaw is that it ignores the problem. Secondly, the use of average prices in place of marginal prices can lead to inaccurate estimates of price elasticities (Billings and Agthe, 1980).

The second class of solutions uses a variation on the reduced form method of dealing with simultaneity bias. The idea common to methods within this class is that in addition to using marginal price as an explanatory variable, another price related explanatory variable should be included which captures the impact of the structure of intramarginal price blocks on water demand.

Billings and Agthe (1980) first proposed adoption of a method introduced by Taylor (1975) and subsequently modified by Nordin (1976). The Taylor-Nordin method uses two price related variables in the demand function. One variable is simply the marginal price for the observed level of withdrawals. The second is called a 'difference variable' and is defined as "the difference between the consumer's actual utility bill and what would have been paid if all units of the commodity were purchased at the marginal price" (Billings and Agthe, 1980, p. 74). The first variable is meant to capture substitution effects while the second is designed to capture income effects.

Griffin and Martin (1981) present a theoretical justification for the use of the Taylor-Nordin method but caution against its implementation. They note that observation errors could imply that observed quantities would not be in the same price blocks as the true quantities. As a result, the estimation of demand parameters may still depend on the price rate structure and the Taylor-Nordin method will not solve the simultaneity problem if observation errors are larger than some critical level. The obvious problem is that the 'critical level' cannot be determined prior to estimation.

There have been two responses to the Griffin and Martin observation. Billings and Agthe (1981) admit the problem exists but argue that exposte a researcher can use estimated residuals in order to identify 'suspicious' data points (i.e. quantity observations likely to be in a price block different from that of the true value) and re-estimate the demand function without them. With a large data set this method is not likely to be feasible. A second response to Griffin and Martin attempts to generate estimates of the marginal price and difference variable which are constant over the entire data set. Billings (1982) proposes the following strategy. Total revenue from water sales is computed for a given rate structure. Next the following equation is estimated: TR = a + b Q + u (where Q is total water withdrawals, (a) and (b) are estimable coefficients and (u) is an error term). Then the estimate of (b) acts as a proxy for marginal price and the estimate of (a) serves as a proxy for the difference variable. As the estimated coefficients are constants the Griffin-Martin problem is avoided.

The third class of methods employs an instrumental variables approach. This is perhaps the most accepted econometric technique to deal with the biases introduced into OLS estimation by simultaneity. The heart of the two stage estimation procedure involves replacing the endogenous explanatory variable (in this case, marginal price) with an estimate derived by regressing the variable against a set of 'instruments' (i.e. a set of variables highly correlated with the explanatory variable but orthogonal to the error term). It can be shown that this procedure yields consistent, unbiased parameter estimates (Kmenta, 1971; Maddala, 1977). This method has only recently been proposed in the context of modeling water demands. It is discussed (but not implemented) by Terza and Welch (1982) and is implemented by Jones and Morris (1984). The common problem underlying this approach is to choose the set of instrumental variables correctly.

It is important to note that these more sophisticated methods of dealing with the simultaneity bias problem are feasible because all of the observations are assumed to be faced with the same price structure. Thus, Jones and Morris (1984) use a single municipality's water block rate structure as the instrumental variable in their estimation model. In the case of a data set drawing observations from several jurisdictions, this procedure is less attractive. For example, the British Columbia firms responding to the Industrial Water Use Survey face a variety of water price schedules and yet they do not all face one, common, block structure as they do not all have provincial licences.

The last area of applied economic water research to be considered here concerns the valuation of industrial water use. This review will not cover the valuation of in situ water uses (see Muller, 1985; Russell and Vaughan, 1982; Adamowicz and Phillips, 1983) nor will it consider the problem of applying a value to water itself independent of its value in use (cf. Mitchell, 1984).

The question alternative valuation methods attempt to address is 'how much would a firm value one more unit of intake water?'. There is one (computationally difficult) method which directly answers this question and several others which, recognizing the difficulty of a precise answer, attempt to provide lower or upper bounds to this value.

A firm's willingness to pay (i.e. its valuation) for one more unit of intake water is just equal to that unit of water's contribution to the firm's profits. Because the firm's profit level, in general, depends on the quantities of inputs it is currently employing, so too does the firm's marginal valuation of water. The firm's valuation of water, then, is not generally a constant but depends on the quantities of other inputs used by the firm.

In principle, an input's marginal contribution to a firm's profits can be estimated. Unfortunately, this type of research (on water's marginal contribution to profits) has not been conducted in Canada.[2] A procedure which closely follows this method, however, has been used to estimate farmers' valuation of irrigation water (Bowden, 1985). The procedure for 'residuals imputation' (Young and Gray, 1972, Chapter 7) subtracts all non-water input costs from total revenue and assigns the residual as the gross return to irrigation. Values of $100 - 200 per hectare have been computed

---

2 Chapter VII presents this study's attempts at this type of estimation.

using this method (Bowden, 1985, 12). The procedure, however, is very sensitive to the definition of non-water input costs (particularly capital costs). In addition, the inclusion of a risk premium in the cost of capital is an unresolved issue. These difficulties aside, however, this method of residuals imputation appears to be a promising source for future estimates of industrial water use valuation.

An alternative procedure which provides an upper bound to the value of water considers the cost of replacing intake water with the 'next best substitute'. In most of the industrial valuation literature this idea has been interpreted to mean that the value of industrial water intake may be approximated by the cost of recirculating an additional unit of water (Young and Gray, 1972; Mitchell 1984; Muller, 1985). The major problems associated with this perspective are that cost estimates are usually restricted to engineering cost estimates and that recirculation is almost always assumed to be the least cost alternative to additional water intake. A more detailed modeling of the production technology may reveal that the substitution of other inputs (labour, capital or materials) may be the most efficient way to decrease water use.

A third method estimates a lower bound to the firm's valuation of water. According to economic theory, the firm should adjust its input use so that each input's marginal cost is just equal to the marginal benefits it provides to the firm. At the margin, then, the cost of intake water indicates the marginal value firms attach to water use. Assuming water use is characterized by declining marginal productivity, however, indicates that using the marginal cost of intake water would usually underestimate the firm's valuation of intake water.

All of these methods are procedures for estimating the private valuation of a social (i.e. publicly administered) resource rather than the social valuation of the private use of a resource. The two values may, in fact, diverge significantly. The use of irrigation water is an excellent example. In Bowden (1985), the private farmer's valuation of delivered irrigation water was estimated to be between $100-200 per irrigated hectare per year. But if the costs of delivery exceed this figure then the social valuation of the water use is negative. Unfortunately, the question of the social optimality of water use is a topic beyond the scope of this study.

C. Institutional Framework

In this section the legislative and institutional framework which regulates the withdrawal, use, and discharge of water by firms in British Columbia is outlined.

The provinces are generally regarded as the proprietors or owners of water resources within their boundaries (except for National Parks and other federal lands). They therefore have the basic authority to manage water resources, licence uses, regulate flows and levy fees. The principle piece of legislation used in British Columbia for these purposes is the British Columbia Water Act (RSBC ch. 429, 1984).

Under the Water Act permission to withdraw water from a stream must be obtained from the provincial government. The use of groundwater or unrecorded stream water for domestic purposes does not require permission[3]. The provincial government grants permission by issuing a licence which specifies how much water the user may withdraw from a given water body and for what purpose. The issuance of a licence, however, does not imply a guarantee to a constant supply of water.

From an economic perspective the important feature of the licensing system is the set of application and rental fees which must be paid by the water user. To many companies which do not rely on municipal water utilities these fees are the only external 'price' they face. The actual rates charged are specified in the regulations to the Water Act and are subject to change by an executive order in council. The fees levied on water users vary by purpose of use and with quantity of water withdrawn. In addition, the application and annual rental fees are in the form of a declining block structure. An example of the nature of the fees charged is presented in Table 5.1.

3 Unrecorded water is the supply available in a stream in excess of the total quantity for which licences have been issued by the provincial government.

If instead of relying on a direct source for intake water, a firm uses a public utility to obtain its intake water then it is subject to the water rates charged by the utility. These rates vary enormously across the province. According to a 1982 survey of municipal water utilities (British Columbia Water and Waste Association, 1982) the majority of utilities charge commercial and industrial users either with a flat per unit charge or with a declining block rate structure. The relevance of municipal water pricing arrangements is limited for this study, however, as less than five percent of British Columbia manufacturing water intake is supplied by public utilities (Tate and Scharf, 1985).

D. Summary

This chapter has provided some of the background information necessary to understand an econometric investigation of British Columbia's industrial water demands. The first section reviewed some of the relevant economic literature and indicated the limitations of that body of literature. An important continuing concern was identified as the defining of the price of water and the construction of applied models which can overcome the potential simultaneity problems associated with using block rate price structures. The second section outlined the significant institutional features relevant to industrial water demands. Having provided this background information, the physical characteristics of British Columbia industrial water use may now be examined.

CHAPTER III

WATER USE IN BRITISH COLUMBIA MANUFACTURING

A. Introduction

The purpose of this chapter is to describe how the British Columbia manufacturing industry used water in 1981. Statistics on water intake, treatment, recirculation and discharge, broken down by two digit Standard Industrial Classification (SIC) code will be presented. As well, the sources of industrial water will be discussed. Most of the statistics on water use shown in this chapter are derived either from Tate and Scharf (1985) or directly from the 1981 Industrial Water Use Survey data.

Before proceeding it is important to make note of the difference between water use and water demands. Unfortunately, these terms are often used interchangeably in the water management literature while they mean two quite different things. Water use describes the physical quantity of water involved in a particular process. For example, in 1981 the British Columbia Petroleum Refining industries had a total (untreated) water intake of approximately sixty-six million cubic metres. In contrast, the demand for water describes the economic relationship between the price of water and the quantity of water desired by the firm or industry. This demand relationship is the basis for determining the value or willingness to pay for the use of water. Discussion of the theory and estimation of demand and value for water is postponed until subsequent chapters while the current chapter examines only the actual water use by industries in British Columbia.

B. Industrial Water Use

It is safe to say that every company in British Columbia uses water. However this 'use' can vary from a few litres per year used to make coffee in the lawyer's office to the millions of cubic metres used every year by foundries to cool molten metals. How, then, can industrial water uses be classified? Indeed what is meant by 'using' water?

Water can be used in basically three ways. First, it can be removed from its natural source, employed to perform some function and then discharged into the environment unchanged in quality (in terms of acidity, temperature, content of organic or inorganic wastes, etc.). An example of this type of water use is the water wheel which was placed in a river in order to harness the force of flowing water to drive a milling operation. In this simple process, water is diverted from the stream only for a few seconds and is returned unchanged to the stream. A second use, mining, resembles the first but results in some change to the water's quality while not changing the quantity available to downstream users. A mine may divert a river and use the water to move coal in slurry form to its processing plant. Once used, almost all of the water is returned but in a degraded form. Finally, the third class of use involves the consumption of all or some of the diverted water supply. The amount of water that a brewery discharges from its plant is substantially less than its water intake (it may also be changed in quality) because water is an ingredient to the production of beer. Thus, users downstream from the brewery have less water available to them then they would if the brewery were not operating.

This classification of water uses is very important for differentiating among firms who would withdraw water from the environment for private use. Nuclear power generating stations withdraw enormous amounts of water to produce electricity but almost all of this water is returned to the environment unchanged except for possible temperature increases. On the other hand, the Food and Beverage industry withdraws a much smaller amount of water (representing approximately four percent of 1981 manufacturing withdrawals in Canada) but consumes a large portion of its water intake. As well, if its discharge water were not treated, the Food and Beverage industry would return the unconsumed water in a substantially altered form, ie. with an altered temperature and higher content of organic wastes. For a more detailed discussion of the alternative uses of water and their relative significance for identifying water shortages and for water planning and management the reader is referred to Foster and Sewell (1981).

Table 3.1 shows the annual intake, discharge and consumption (intake minus discharge) flows for each industry group. The last column shows the ratio between consumption and intake. The Non-Metallic Mineral Products industry is by far the highest unit 'consumer' of

TABLE 3.1

Industrial Water Use in British Columbia

(millions of cubic metres per year)

Industry Group	Total Intake	Total Discharge	Total Consumption	Ratio of Consumption to Intake
Total: British Columbia	2181.732	2116.086	65.646	.030
Food & Beverage	34.649	32.769	1.880	.055
Rubber & Plastic Products	.967	.943	0.035	.037
Textile	.224	.217	0.007	.032
Wood	62.180	60.039	1.036	.017
Paper & Allied Products	817.679	762.631	55.048	.068
Primary Metal	1110.373	1109.940	0.433	.001
Metal Fabricating	2.375	2.317	0.058	.065
Transportation Equipment	1.557	1.457	0.100	.065
Non-Metallic Mineral Products	5.126	3.578	1.548	.302
Petroleum & Coal Products	66.163	62.398	3.765	.057
Chemical & Chemical Products	80.439	79.808	0.631	.008

water. In contrast, the largest water user, the Primary Metals industry, consumes almost no water (one-tenth of one percent of water intake). An awareness of these differences is essential for the development of water management policies.

Another way to consider industrial water use is to examine the role water plays in the production process.[1] Water intake may be broken down into the amounts withdrawn for cooling, condensing and steam generation, process, sanitation and other. The first category of water intake refers to water use for the production of steam. Process water is water that comes in contact with an intermediate or final product of the manufacturing process. Sanitation is

1 These definitions are drawn from Tate and Scharf (1985).

self-explanatory. Other water uses include watering lawns and filling ornamental pools.

Table 3.2 provides a breakdown of water intake by purpose for British Columbia manufacturing. Several interesting features emerge from this table. First, more than 95 percent of total water intake is concentrated in four industry groups: Primary Metals, Chemicals, Paper and Allied Products, and Petroleum and Coal Products. These are the 'big four' manufacturing water users. Second, most water intake is used for cooling, condensing and steam generation. If the Paper and Allied group is excluded, then 93 percent of British Columbia manufacturing water intake is used for that purpose.

TABLE 3.2

Water Intake by Purpose in British Columbia

(millions of cubic metres per year)

Industry Group	Total Water Intake	Processing	Cooling Condensing & Steam	Sanitary Service	Other
Total: British Columbia	2181.498	732.800	1399.567	46.563	2.568
Food & Beverage	34.613	10.817	20.002	2.836	.958
Rubber & Plastic Products	.953	.214	.691	.045	.003
Textile	.224	.117	.098	.009	0.000
Wood	62.121	18.041	40.033	3.812	.236
Paper & Allied Products	817.671	682.172	126.857	8.175	.467
Primary Metal	1110.363	2.597	1077.299	30.466	0.000
Metal Fabricating	2.370	1.131	1.071	.168	0.000
Transportation Equipment	1.542	.385	.400	.344	.413
Non-Metallic Mineral Products	5.080	1.843	2.905	.258	.074
Petroleum & Coal Products	66.163	2.568	62.942	.245	.408
Chemical & Chemical Products	80.397	12.916	67.270	.202	.009

Source: Tate and Scharf, (1985), Volume I, table 1.08

Having seen how water enters the production process for British Columbia manufacturing, the manner in which these industries use water may be illustrated. After using water once (eg. for cooling), the firm must decide whether to withdraw more water from the environment and discharge (and possibly pretreat) the used water or, instead, to recirculate (and possibly treat) the once used water and reuse it. The decision will depend on the nature of the production process and on the relative costs of each option. Table 3.3 provides information on how water is used in British Columbia manufacturing industries.

Table 3.3 indicates that the 'big four' water users are also the

TABLE 3.3

Water Use by Industrial Group in British Columbia

(millions of cubic metres per year)

Industry Group	Total Intake	Total Treated Intake	Total Recycled Water	Gross Water Use	Total Discharge	Total Treated Discharge
Total: British Columbia	2181.732	3071.645	3689.803	4871.535	2116.086	651.520
Food & Beverage	34.649	19.188	8.931	43.579	32.769	12.342
Rubber & Plastic Products	.967	.102	556.057	557.024	.943	.032
Textile	.224	.098	.048	.272	.217	.052
Wood	62.180	32.320	52.721	114.901	60.039	5.263
Paper & Allied Products	817.679	836.862	1541.014	2358.693	762.631	557.041
Primary Metal	1110.373	2020.252	388.665	1499.038	1109.940	30.710
Metal Fabricating	2.375	.104	2.548	4.923	2.317	1.186
Transportation Equipment	1.557	.108	.043	1.600	1.457	.028
Non-Metallic Mineral Products	5.126	2.050	3.929	9.055	3.578	.219
Petroleum & Coal Products	66.163	68.678	115.077	181.240	62.398	29.428
Chemical & Chemical Products	80.439	91.883	20.771	101.210	79.808	15.220

Source: Tate and Scharf, (1985), Volume I, table 1.03

industries which treat the largest quantity of water (relative to intake and discharge). In addition the industries which recycle water most within the production process (relative to intake) are Wood, Paper, Metals and Chemicals (the figure for the Rubber and Plastic Industry's recycled water is almost certainly inaccurate as it suggests that industry recycles water 500 times). A significant feature of this table, then, is the variablity of water use across industries in British Columbia.

We now have a fairly good picture of how the British Columbia manufacturing industry uses water. But where does this water come from? Table 3.4 breaks down water intake by source for fresh water and brackish water.

TABLE 3.4

Water Intake by Source in British Columbia

(millions of cubic metres per year)

Industry Group	Total	FRESH WATER Public	FRESH WATER Self-Supplied Surface	FRESH WATER Self-Supplied Ground	FRESH WATER Other	BRACKISH WATER Self-Supplied Ground	BRACKISH WATER Self-Supplied Tide	BRACKISH WATER Other
Total: British Columbia	2181.498	54.989	2025.525	27.012	.678	.219	72.996	.079
Food & Beverage	34.613	19.476	8.529	.983	.000	.000	5.625	.000
Rubber & Plastic Products	.953	.902	.046	.005	.000	.000	.000	.000
Textile	.224	.178	.018	.028	.000	.000	.000	.000
Wood	62.121	11.514	20.562	.722	.000	.000	29.322	.000
Paper & Allied Products	817.671	1.216	791.584	24.871	.000	.000	.000	.000
Primary Metal	1110.363	.768	1109.594	.000	.000	.000	.000	.000
Metal Fabricating	2.370	2.360	.010	.000	.000	.000	.000	.000
Transportation Equipment	1.542	1.448	.094	.000	.000	.000	.000	.000
Non-Metallic Mineral Products	5.080	1.801	2.916	.364	.000	.000	.000	.000
Petroleum & Coal Products	66.163	4.763	61.401	.000	.000	.000	.000	.000
Chemical & Chemical Products	80.397	10.563	30.771	.037	.678	.219	38.049	.079

Source: Tate and Scharf, (1985), Volume I, table 1.11

One feature of Table 3.4 is immediately apparent. Most firms in British Columbia manufacturing are self supplied. For all of British Columbia manufacturing, self supplied (fresh and brackish) water represents 97 percent of total water intake. For the 'big four' industries (Primary Metals, Paper and Allied Products, Petroleum Products and Chemical Products) the figure is 99 percent. These statistics are very important for managers of British Columbia's water resources. They indicate that the Water Act and its attendant regulations and rental fees must be the tool used for regulating water use. Municipal water rates, while potentially significant for regulating urban domestic and commercial water demands, are almost irrelevant to British Columbia's industrial water demands with the possible exceptions of the Food and Beverage, Metal Fabricating and Transportation Equipment industries. These latter industry groups are characterized by relatively small firms in urban centres which rely on public utilities for intake water.

The significance of the preceding information is reinforced by an examination of Table 3.5. Just as most British Columbia manufacturers are self supplied for their water withdrawals they also rely on points other than public sewers to discharge their water. Only 3 percent of all industrial water discharges are into a public sewer system. The industries relying on public sewer systems are those which are primarily located in large urban centres.

Table 3.6 details water use in British Columbia manufacturing

TABLE 3.5

Water Discharge by Discharge Point in British Columbia

(millions of cubic metres per year)

Industry Group	Total	Public Sewer	Freshwater Body	Tidewater Body	Ground	Trans-ferred Other
Total: British Columbia	2115.904	56.651	460.018	1581.810	17.385	.040
Food & Beverage	32.734	13.329	9.322	9.105	.971	.006
Rubber & Plastic Products	.918	.848	.052	.000	.018	.000
Textile	.217	.154	.064	.000	.000	.000
Wood	59.989	1.881	27.986	29.069	1.020	.033
Paper & Allied Products	762.623	3.664	229.581	517.533	11.845	.000
Primary Metal	1109.930	30.189	100.297	979.190	.254	.000
Metal Fabricating	2.312	.775	1.168	.000	.368	.001
Transportation Equipment	1.442	.576	.262	.593	.011	.000
Non-Metallic Mineral Products	3.565	.342	2.575	.046	.603	.000
Petroleum & Coal Products	62.398	2.593	58.797	.997	.012	.000
Chemical & Chemical Products	79.775	2.302	29.913	45.279	2.281	.000

Source: Tate and Scharf, (1985), Volume I, table 1.20

industries relative to number of employees and to value of output. These standardized figures allow meaningful comparisons across industries which take into account differences in scale among industries.

Table 3.6 indicates that there is enormous variability in water intake per employee and per dollar of output among British Columbia industrial water users. Interestingly, the 'big four' water users are also the highest water users per employee and per dollar of output.

TABLE 3.6

Water Use Relative to Employment and Output in British Columbia

Industry Group	Number of Employees[1]	Value of Output[2]	Intake/ Employees[3]	Intake/ Value of Output[4]
Total: British Columbia	76200	8856.2	28.7	0.2464
Food & Beverage	13800	1690.2	2.6	0.0205
Rubber & Plastic & Textiles	1274	77.1	1.0	0.0152
Wood	23980	2131.0	2.6	0.0290
Paper & Allied Products	15652	2197.0	52.3	0.3722
Primary Metal	6927	624.5	160.3	1.7781
Metal Fabricating	6027	505.3	0.4	0.0047
Transportation Equipment	1929	93.7	0.8	0.0167
Non-Metallic Mineral Products	3001	312.5	2.0	0.0170
Petroleum & Coal Products	1480	1620.1	45.1	0.0411
Chemical & Chemical Products	2128	347.1	38.0	0.2324

NOTES:

1. Source: Tate and Scharf, (1985), Volume I, table 1.03
2. Computed by finding the ratio of Total Employees, (for respondents to the Industrial Water Use Survey) to Total Employees, all of British Columbia (Source: Statistics Canada, SC 31-203, 1981) and multiplying this ratio by Total Value of Output, British Columbia Manufacturing (Source: Statistics Canada, SC 31-203, 1981). Measured in millions of dollars.
3. Measured in thousand cubic metres per employee.
4. Measured in cubic metres per dollar of output.

C. Summary

This chapter has provided some statistics on how British Columbia industry uses water. It was shown that most firms are self supplied, most water withdrawn is used for cooling purposes and that water use is concentrated in four industries.

The statistics reported would suggest that future water demand studies may profitably be concentrated on the 'big four' water using industries. In the discussions on the empirical results that follow an attempt is made emphasize their significance for these four industries.

CHAPTER IV

DATA AND ESTIMATION METHODS

A. Introduction

This chapter will detail the nature of the data set and the methodologies used in the estimation of intake water demand equations for British Columbia manufacturing. As well, the basic economic theory underlying the model formation will be discussed. Readers already familiar with the principles of the economic theory of derived demand and with the techniques of OLS estimation may proceed immediately to the next two chapters which report on the estimation results.

B. Data

In 1981 Environment Canada, in conjunction with Statistics Canada, carried out the Industrial Water Use Survey. Questionnaires were sent to almost 5,000 manufacturing firms requesting detailed information on their uses of and expenditures on water[1]. Environment Canada received approximately 3,300 responses from all over Canada and these were coded into a computer file. For this study only the set of responses from the British Columbia manufacturing sector were used. Table 4.1 provides a breakdown of

---

1 The Industrial Water Use Survey sent questionnaires to not only the manufacturing industry but also the mining industry and to firms and utilities involved in power generation by either thermal or hydro electric means. We report on our study results for the "Mining" data set in Appendix A.

the 372 responses from British Columbia by two digit SIC code level industry. The empirical results reported in this paper will be presented using the same industry breakdown as seen in Table 4.1.

TABLE 4.1

Number of Observations by Industry from British Columbia National Water Use Survey

SIC	Industry Group	Number of Observations
37	Chemicals and Chemical Products	40
36	Petroleum and Coal Products	7
35	Mineral Products	51
32	Transportation Equipment	13
30	Metal Fabricating	18
29	Primary Metals	9
27	Paper and Allied Products	76
25	Wood Products	28
18	Textiles)	
16	Rubber and Plastics)	30 [1]
10	Food and Beverages	100
	TOTAL	372

NOTES:

1. The Textiles and Rubber and Plastics industries will be combined and treated as a single industry due to the relatively small number (4) of observations on the Textile industry.

The Industrial Water Use Survey contained questions regarding the quantities and expenditures on water intake, treatment, recirculation and discharge. As well the survey identifies the source of intake water and the point of discharge for discharge water. These figures are important for determining water rental costs based on provincial and municipal licensing regulations. The survey also asks for employment data and information regarding the firm's product and production process.

In addition to the Industrial Water Use Survey there are two other sources of water cost data. First, the provincial Ministry of Environment supplied information on water rental fees and water licence fees for firms with private intake sources. The British Columbia Water and Waste Water Association (1984) provided detailed information on municipal water rate structures throughout British Columbia. These two sources were valuable as they allowed intake water costs to be calculated for a significant portion of those firms which did not supply that information. Finally, Statistics Canada publications supplied data on the value of output for British Columbia manufacturing industries and on expenditures for non-water inputs. The various data sources described here provide an excellent source of information regarding industrial water use in British Columbia. None of the research works discussed in the literature review of Chapter II were based on as comprehensive and detailed a data base as used in the present study.

C. Economic Theory of Demand

In this section the basic economic theory which underlies this study's modeling of industrial water use and the econometric methods employed to characterize water use technology are discussed. This section will introduce and define several important economic concepts. More detailed discussions of these concepts and of the related economic theory can be found in Russell and Wilkinson (1979) and Varian (1981).

A basic conceptual tool used in the economic theory of the firm is the production function. This is a functional statement relating the levels of various inputs to the maximum output a firm can produce. In equation (1), $X_1, \cdots, X_n$ denote the n inputs used (for example, the inputs could be labour, capital, intermediate materials and water and in this case n = 4) and Q is the maximal level of output associated with the specified levels of inputs:

$$(1) \quad Q = f(X_1, X_2, \cdots, X_n)$$

Equation (1) implicitly defines the form of technology used by the firm. The specific form chosen to depict the function indicates the role each input plays in the production process.

The production function only relates quantities of inputs to quantities of output. As a result it is a description of what is technologically feasible. In order to determine what is economically optimal for the firm to do, however, the prices of the inputs and outputs must be considered.

Prices are of paramount importance to the economic modeling of decision making. To the purchaser of a productive input, the price indicates that the input is a scarce one and that it has alternative uses. Thus, the purpose of charging a price for an input is to force the firm to 'internalize' the fact that it is depriving another firm of the use of that input. If an input has zero price (like much of Canadian water) then the firm will perceive no shortage and will overuse the input.

Including prices into the model of the firm allows for a much richer picture of industrial decision making. When choosing the appropriate input 'mix' to produce a certain output the firm must now consider the technology confronting it and also the relative costs of the available inputs. A central assumption employed in modeling the firm's decision-making is that of <u>cost-minimizing behaviour</u>. For a given level of planned output, a given type of technology and a given set of input and output prices, firms <u>are assumed</u> to choose their input mix so as to minimize the cost of producing the planned level of output. This assumption is more powerful than it would seem for it directly implies the existence of input demand equations (cf. Russell and Wilkinson, 1981, Chapter 9).

An input demand function relates the desired quantity of a particular input (eg. skilled labour) to the following economic variables: the level of output planned by the firm, the price of the input and the prices of all of the other inputs employed by the firm. Thus, when an economist speaks of the firm's demand for water, he/she is talking about a functional relationship between the firm's desired level of water use and the firm's output and the input prices it faces. Mathematically, a demand equation is depicted something like equation (2) where X_i is the desired level of the i^{th} input, Q is the output level of the firm and $P_1 \cdots P_n$ are the input prices facing the firm:

$$(2) \quad X_i = g_i(Q, P_1, \cdots, P_n)$$

The economic theory of the firm's demand for inputs suggests that the demand equation should satisfy certain characteristics. First, the quantity demanded should be a decreasing function of the price of the input and an increasing function of the firm's level of output. Second, the demand equation is assumed to be 'homogeneous of degree zero' in prices. This means that if all the input prices double, the optimal quantity of each input will not change (since relative input costs have not changed). These assumptions can be tested using the estimated demand equations. If a firm uses more than one input then it must simultaneously choose the optimal levels of each input. A firm then optimizes over a system of interrelated demand equations, one equation for each input.

An accurate picture of the form of a firm's input demand equations is obtained through statistical estimation. This procedure requires collecting data on the relevant economic variables, choosing an estimatable functional form for the demand equation and then statistically estimating the values of the unknown parameters of the demand equation. The details of this procedure are discussed in Section D of this chapter. Once the demand equation parameters have been estimated several important economic statistics can be computed. These include each input's 'price elasticity', 'output elasticity' and the cross-elasticities between each pair of inputs.

The concept of elasticity is perhaps the most important statistic generated by applied economic work. Simply put, the elasticity of X with respect to Y is measured by the percentage change in X when Y changes by one per cent[2]. Thus, the own price elasticity of water intake demand is equal to the percentage change in the firm's optimal level of water intake when the price of intake water changes by one per cent. If water use changes by less than one per cent as a result of a one per cent price change, demand is said to be 'inelastic'. The converse case (a one per cent price change inducing a greater than one per cent use change) is denoted as an 'elastic' demand. Finally, if a per cent price change leads to an equal per cent use change then demand has 'unitary' elasticity. The definition of an input's own output elasticity is analogous to its own price elasticity; it represents the percentage change in the use of a particular input resulting from a one percentage change in the level of planned output. Thus, if it were found that the output elasticity of intake water was 0.95 then this could be interpreted

---

2 This is an approximate formula. More accurately, the elasticity of X to Y (denoted E_{xy}) is given by:

$$(3) \quad E_{xy} = \frac{dx}{dy} \cdot \frac{y}{x}$$

as meaning that a one per cent growth in the output level of the firm would entail a 0.95 per cent increase in the firm's water intake.

Another set of important economic statistics which can be computed from the estimated demand equation parameters are the cross-elasticities between inputs. This relates the percentage change in the desired level of input i to the percentage change in the price of input j, holding the level of output constant. If the cross elasticity is less than zero, this indicates complementarity in the use of inputs i and j. Alternatively, a value greater than zero shows that the inputs are substitutes in the production process and a value of zero indicates no substitution possibility between the two inputs. The cross-elasticity is an important economic statistic because it shows how inputs are related and it measures the ease with which relatively inexpensive inputs may be substituted for relatively scarce and expensive resources.

Before proceeding to a discussion of the estimation procedures used in this study two technical issues of economic theory should be mentioned. They both involve assumptions regarding the production structures of the firms under study which are implicit to the estimation methods used here. The first assumption concerns aggregation. Thus far we have discussed these theoretical economic issues at the level of the individual firm but our estimation will be carried out at the industry level. In order for that estimation to be valid, it is necessary to assume that the firms in the industry have a sufficient degree of commonality in the production structures. This will allow observations to be drawn from firms and to consider them as separate observations from the same entity - namely, the industry being studied. That is, it is assumed that the individual firms within the industry are similar enough that they can be aggregated and treated as a single firm. Thus, in the next chapter, the Food and Beverage industry's demand for intake water will be reported rather than the individual firms' (which make up that industry) demand for intake water.

The second touchy issue underlying the estimation procedure concerns the assumed separability between inputs. A pair of inputs is said to be separable from the other inputs employed if the elasticity of substitution between them is unaffected by the levels of the other inputs. If we assume, for example, that water intake and labour are separable from all other inputs then we can estimate those input demand equations (simultaneously) in isolation from the other inputs. Thus, maintaining the assumption of separability may impose strong pre-conditions on the structure of the production process but also can substantially reduce the data collection requirements of a project. Because of data limitations, most of the empirical analysis of this study will assume that water intake demands are separable, and can therefore be studied in isolation from other inputs.

This would seem to be a good point to indicate a more sophisticated model of input demands which will form the basis for future work. We have already indicated that the optimal level of one input generally depends on the price of other inputs. A more complete modeling of the firm's decision making would also show that the optimal level of any input depends on what the firm expects to be the optimal level of its other inputs. That is, the optimal level of all inputs really should be determined simultaneously. Thus a major future project involves the modeling and simultaneous estimation of a system of water use demand equations for each industry sub-group.

There is also a second, slightly more general, project planned for the future. A cost function for the entire British Columbia manufacturing industry will be estimated. A cost function is an alternative way to depict the firm's technology (i.e. it provides the same information as the production function). The cost function will be modeled to include water as an input. The relationships between water use and the use of other productive inputs may then be determined.

The purpose of this section has been to briefly review some of the key economic definitions important for understanding the discussion of the empirical results in the following chapter. Before that discussion, however, the estimation procedures used to derive the results will be detailed.

D. Estimation Methods

In this section the econometric methods used to estimate water demand equations for British Columbia manufacturing industries will be detailed. The method of generating a price of water variable is first discussed.

Defining the price of water remains a significant unresolved issue for applied water demand analysis. Ideally, the analyst wants to model water demands by assuming price is given to the decision maker and, thus, treat it as an exogenous explanatory variable. If the price of the good is jointly determined with the level of consumption (as would be true in the case of a block rate pricing structure) then the estimation of a demand equation incorporating price as an explanatory variable could involve a simultaneity bias in the estimation of parameters. (cf. Kmenta, 1971, Chapter 13 and the discussion in Chapter II of this report). This problem also arises when only expenditure and quantity data are available and price is proxied by average cost. Indeed, several of the highly aggregated water demand studies discussed in Chapter II used this method of generating a price proxy while recognizing the potential for biased estimates (Babin, et al. 1982; Field and Greberstien, 1979).

The standard procedure to deal with this simultaneity problem involves the use of instrumental variables estimation (Maddala, 1977, Chapter 11). Unfortunately, in the case of the British

Columbia manufacturing industry, most firms face no common external price schedule for their water intake and, thus, there is no clear candidate for instrumental variables. Thus while the procedure described here to generate price proxies is somewhat more sophisticated than the 'average cost proxy' method it does not deal adequately with the simultaneity problem. The identification and use of instrumental variables in this context certainly merits future study.

The method of generating a price for water used in this study extends a procedure suggested by Ziegler and Bell (1984). Observations on the firm's expenditures on and quantities of water use are employed to regress the following equation:

$$(4)\quad TC = a_0 + a_1Q + a_2(Q)^2$$

where TC is total expenditure on a given category of water use, Q is total quantity of water use and a_0, a_1 and a_2 are unknown parameters. Thus, it is assumed that water use costs are quadratic in form. Once equation (4) has been estimated using OLS methods then the following two price proxies are constructed:

$$(5)\quad MC = \hat{a}_1 + 2\hat{a}_2Q$$

$$(6)\quad AC = \hat{a}_0/Q + \hat{a}_1 + \hat{a}_2Q$$

where MC is the estimated marginal cost of water use (derived by differentiating equation (4) with respect to quantity), AC is the estimated average cost of water use and $\hat{a}o_1$, $\hat{a}_1$ and $\hat{a}_2$ are parameter estimates from equation (4). We now have three proxies for the price of water: the computed average cost (ACB = TC/Q), the estimated average cost [from equation (6)] and the estimated marginal cost [from equation (5)]. Each one of these may be used in the estimation of water demand equations and their respective explanatory power may be compared.

The sparceness of the data set provided by the Industrial Water Use Survey necessitated the use of another constructed proxy variable. While economic theory dictates that the level of output be included as an explanatory variable in the water demand equations this information was not collected in the Survey. As a proxy for output we construct a variable, total employee hours, which is defined as total days of operation per year times average number of employees per year times average hours of operation per day. These three separate variables are all available from the Survey. This constructed variable will act as a 'good' proxy for output if labour and output are strongly correlated and if labour and water use are separable. Unfortunately, the data set available does not allow testing these hypothesis.

Before proceeding to the estimation of the water demand equations one further data-related issue merits discussion. The Industrial Water Use Survey questionnaires were plagued with poor response rates on the cost of water use questions. Yet it was unclear, on economic grounds, whether these observations should be omitted. Using only the non-zero cost observations would certainly generate a more credible set of results but would result in the omission of a substantial portion of the data set. As a result of this uncertainty, the estimation of the price proxies was conducted both with the whole data set and with an abbreviated data set representing only the non-zero cost observations.

The estimation of an industry's water demands should be conducted as part of a larger characterization of the industry's technology. For example, the estimation of a production function for an industry would allow water demands to be estimated simultaneously with the other input demand equations. Data limitations on non-water inputs prohibited this being done[3]. As a result, single equation water intake demand equations were estimated. In the absence of a chosen functional form for the production or cost function, there was little guidance to the required functional form for the demand equation. Two functional forms were adopted: logged dependent and linear independent variables (equation (7)); and linear dependent and logged independent variables (equation (8)). The estimated water demand equations, then, had one of either of the following forms:

---

3 As well, problems with the computer econometrics package's sub-routine responsible for estimating systems of equations forced postponement on that stage of the study.

(7) $\log(QIN) = a_0 + a_1PIN + a_2PTRT + a_3PRCR + a_4POUT + a_5THR + u$

(8) $QIN = b_0 + b_1\log(PIN) + b_2\log(PTRT) + b_3\log(PRCR) + b_4\log(POUT) + b_5\log(THR) + v$

Where:

QIN = total water intake
PIN = price of water intake
PTRT = price of water treatment
PRCR = price of water recirculation
POUT = price of water discharge
THR = total employee hours
u,v = error terms

It should be noted that each price term was proxied by the three different available proxies (as described earlier in this section) and that OLS techniques were used throughout.

E. Summary

Many of estimation methods described here are far from ideal and yet would seem to be the most sophisticated methods the data set would allow. Future work will be concentrated on investigating the use of instrumental variables in the construction of price proxies and the estimation of water demands as a simultaneous system of equations. The next chapter reports on the results of the estimation of water intake demand equations for the British Columbia manufacturing industries.

CHAPTER V

THE COSTS OF WATER USE

A. Introduction

The purpose of this chapter is to detail the costs related to water use in the British Columbia manufacturing industry. The two most significant costs are water rental fees which must be paid to the provincial government or to a municipal utility and in-house operating and maintenance and capital costs for the firm's facilities for water intake, treatment, recirculation and discharge. Each of these is discussed in turn.

B. Water Pricing in British Columbia

A firm in British Columbia wishing to secure a supply of water must either rely on a public utility or find its own source of supply. In the former case it is confronted with a price schedule which specifies the cost of water supply. The nature of these schedules varies enormously throughout the province. Municipalities use a variety of charging methods and reliance is split fairly equally among flat rate charges, metering, and the use of both (British Columbia Water and Waste Association, 1982, table 4.7). The level of charges also varies significantly across municipalities. For instance, the mean annual water intake for a British Columbia manufacturing firm in 1981 was approximately 5.8 million cubic metres. Depending on the location of this hypothetical firm, it would have to pay between $0.1 - 1.2 million (1981 dollars) for its intake water if it relied totally on a public utility (BCWWA, 1982, table 4.3). The size of these intake costs provides an excellent indication why 94 per cent of manufacturing water intake in this province is self-supplied[1]. Firms drawing water from a private source bear only provincial water licence fees and in house pumping and treatment costs.

In order for a private agent to withdraw water from circulation, that person requires a licence as specified in the British Columbia Water Act (RSBC, Ch. 429, 1979). That statute empowers the provincial government to set rental fees for the right to withdraw both surface and ground waters. To date, the government has chosen to set fees only for the withdrawal of surface waters. These fees are set out in the regulations under the Water Act. Table 5.1 illustrates the type of charges provided for under the Water Act.

In addition to paying for intake water either to a public utility or to the provincial government, a firm often has other costs associated with its water use. These are the in-house operating and maintenance costs and capital costs associated with its in-plant system which pumps, treats, stores, recirculates and discharges

---

1 It is difficult to say what the hypothetical self-supplied firm would pay for its water because the responses to the cost of intake question may have included provincial licence costs in addition to in-house operating and maintenance costs. The cost of a Provincial water licence, however, to withdraw 5.8 million cubic metres per year for cooling purposes would be $550 (see Table 5.1).

TABLE 5.1

Sample Calculation of Fees Under the Water Act

Fees for water withdrawn for Cooling Purposes:

	1981($)
Application Fee	
for each 10,000 gallons/day, total less than 500,000 gallons/day	2.0[1]
for each 10,000 gallons/day, total between 500,000 and 1 million gallons/day	1.0
for each 10,000 gallons/day, total greater than 1 million gallons/day	0.5

Rental Fee - same rates as application fees

Thus, if a manufacturing firm had an annual intake of 5.8 million cubic metres per year[2] (the average for British Columbia manufacturing firms) and used all of this water for cooling purposes then it would have to pay a combined application and rental fee of approximately $550 (1981) for that right to the Provincial government.

NOTES:

1. The application and rental fees were all doubled in 1982. Listed in Table 5.1 are the 1981 fee rates.
2. This sample calculation assumes the firm is in operation 365 days per year.

water. While the 1981 Industrial Water Use Survey did not require capital cost information it did ask for operating and maintenance cost information. In the next section this component of the firm's water-related costs is discussed.

C. Internal Costs of Industrial Water Use

In order to obtain and use water in its production process a firm must incur certain costs. These include expenditures to install, operate, maintain and monitor the various systems necessary to bring water to the plant, treat the water to a desired quality, use the water in the production process and then discharge it. In this section some summary statistics from the Industrial Water Use Survey are presented as they relate to water use costs.

Table 5.2 presents the total operating and maintenance cost by use component and by industry. For example, note that the Primary Metal industry spent just over $584,000 (1981 dollars) in order to obtain water. It is important to note however that this figure represents only those expenditures for firms which responded to the Industrial Water Use Survey and also answered the question on water acquisition costs. Nonetheless, some of the results for specific industries are quite interesting. The Pulp and Paper industry is the number one spender on water - largely due to the substantial treatment prior to discharge costs. Food and Beverage is also a large spender on water (having the third largest total water cost). This is attributable to the large amounts of treatment process water must undergo prior to discharge and to the fact that many of this industry's firms rely on public utilities for intake water - a relatively expensive source. Yet, comparisons of water costs across industries in Table 5.2 is made difficult by the differences in size of these industries. A more accurate picture may be obtained by comparing average costs as shown in Table 5.3.

TABLE 5.2

Industrial Water Use Costs by Purpose in British Columbia
($000, 1981 dollars)

Industry Group	Water Acquisition Cost	Intake Treatment Cost	Recirculation Cost	Discharge Treatment Cost	Total[1] Cost
Total: British Columbia	8779.896	5181.181	3361.687	11071.033	28393.797
Food & Beverage	1543.009	280.028	107.600	538.185	2468.822
Clothing & Rubber	54.813	14.539	398.122	1.258	468.732
Wood	1288.948	190.981	308.913	302.165	2091.007
Paper & Allied	3342.760	3766.843	820.107	7513.050	15442.760
Primary Metal	584.115	21.001	5.302	30.003	640.421
Metal Fabricating	160.192	17.657	31.970	342.818	552.637
Transportation	22.210	.003	.003	.003	22.219
Non-Metallic Mineral Products	128.649	25.574	182.841	34.641	371.705
Petroleum & Coal Products	735.640	730.162	1094.227	1782.000	4342.029
Chemical & Chemical Products	919.557	134.389	412.600	526.907	1993.453

Source: Tate and Scharf, (1985), Volume I, table 1.41

NOTES:

1. Column 5 is calculated by summing across columns 1 to 4.

Table 5.3 presents estimates of average or per unit costs broken down by water use component and by industry. It is important to note how these averages were determined. Only those respondents providing a non-zero cost estimate were included in the estimation of these figures. Averaging over the entire data set would have meant underestimating the average cost because of the prevelance of respondences with zero cost observations but non-zero quantity observations. For example, in Table 5.3, the average recirculation cost for the Chemicals industry is given as $36.261/1000m^3. However the 'simple' average (that is, total treatment cost divided by total treatment) is only $19.864/1000m^3.

TABLE 5.3

Computed Average Industrial Water Use Costs in British Columbia
$/1000m^3 per year (1981 dollars)

Industry Group	COMPUTED AVERAGE COST Intake	Treatment	Recircu- lation	Discharge	Total
Food & Beverage	137.06	404.27	989.16	130.04	1660.53
Clothing & Rubber	137.78	114.24	116.10	43.67	411.790
Wood	206.24	28.825	3.12	796.65	1034.84
Paper & Allied	420.27	30.01	1102.90	506.10	2059.33
Primary Metal	1185.9	*1	*1	0.11	1186.0
Metal Fabricating	1988.60	0.15	0.08	*1	1988.8
Transportation	220.90	72.84	1.24	117.88	412.85
Non-Metalic Mineral Products	127.96	319.55	27.20	178.96	653.67
Petroleum & Coal Products	32.83	43.27	39.67	145.43	261.21
Chemicals & Chemical Products	226.37	219.56	36.261	270.56	752.75

NOTES:

1. Estimate less than .01.

One interesting feature of Table 5.3 is that the 'big four' - ie. the top four industries in terms of water intake - Primary Metals, Paper and Allied, Petroleum and Chemicals - also have some of the highest average water use costs. In addition to these four industries, however, it can be seen that the Metal Fabricating and

Food and Beverages industries also have relatively high average costs. In addition, it would appear that for most industries (Primary Metals and Metal Fabricating being the exceptions) the total costs of water use are fairly well distributed among the use components. As well, for most industries, the average costs of discharging water make up a fairly large portion of total average costs.

To an economist, another relevant variable to be considered when studying input use is the marginal cost[2]. This amount essentially indicates the amount the firm spent on the last unit of input it acquired. Unfortunately, in order to compute the marginal cost of water use it is necessary to know something about the relationship between costs and the level of water use. A single observation will not supply this information. However, a method of estimating the marginal cost was discussed in the preceeding chapter. This is the method suggested by Ziegler and Bell (1984) which estimates the relationship between cost of quantity of water use and then derives from this estimated relationship an estimate of the marginal cost (see Chapter IV for details). The estimated mean marginal cost for each water use component and each industry is presented in Table 5.4.

The figures presented in Table 5.4 are quite striking. In every instance (with the exceptions of the marginal cost of recirculation

---

2 Marginal Cost is defined to be the change in total costs for a one unit change in input use (here, a unit is 1000 cubic meters).

TABLE 5.4

Estimated Mean Marginal Cost of
Industrial Water Use in British Columbia

$/1000m³ (1981 dollars)

Industry Group	ESTIMATED MEAN MARGINAL COST Intake	Treatment	Recirculation	Discharge	Total
Food & Beverage	48.3	4.53	10.90	*[1]	63.73
Clothing & Rubber	*	15.32	39.00	*	54.32
Wood Products	4.03	*	*	4.09	8.12
Paper & Allied	42.19	.055	*	*	42.245
Primary Metals	.712	.002	*	.005	.719
Metal Fabricating	25.82	**[2]	**	**	25.82
Transportation	55.29	*	17.78	20.89	93.96
Non-Metallic Minerals	*	*	28.72	*	28.72
Petroleum & Coal Products	50.29	8.16	7.43	98.49	164.37
Chemicals & Chemical Products	18.06	1.06	4.59	25.54	49.25

NOTES:

1. * denotes an estimate less than or equal to zero.
2. ** denotes an insufficient number of observations to estimate.

for the Transportation and Mineral Products industries) the marginal cost of each water use component for each industry is less than the average cost. For example, from Table 5.3 it is seen that the average cost of intake for the Food industry was computed to be $137.06 /1000 m^3 (1981 dollars) while the corresponding marginal cost is estimated to be only 48.30 /1000 m^3 (1981 dollars). In fact many of the estimates of the marginal cost of water use were negative or insignificantly different from zero! A comparison of these two tables yields two tentative conclusions. First, because of the relatively small water use 'prices' charged to firms they have expanded their water use to the point where the marginal costs have been driven almost to zero. Secondly, the fact that marginal costs are consistently estimated to be less than average costs suggests that firms enjoy returns to scale with respect to water use. This, in turn, may be due to the complementarity between water use and capital expenditures. The latter hypothesis certainly merits further investigation. Alternatively, the declining block rate structure common to water pricing schedules in British Columbia may be partially responsible for this difference.

While the above tables indicate the approximate level of expenditures on water by manufacturing industries they do not give a good measure of the importance of those expenditures relative to the total costs borne by the firm. Table 5.5 presents estimates of the share in total costs that water-related expenditures represents. These estimates were constructed by assuming that all British Columbia manufacturing industries under study experience constant returns to scale. In that case total revenue is equal to total cost and the ratio of water expenditures to total revenue (total revenue is available from Statistics Canada publication SC 31-209) is a good approximation to water's cost share. It would appear that water's share of total costs is small - reaching a maximum of only three per cent in the Wood Products industry (for comparison, it is often assumed that the cost shares for labour, capital and materials in

TABLE 5.5

Water's Share in Total Costs
in British Columbia Manufacturing

Industry Group	Water's Cost Share (%)
ALL MANUFACTURING*	0.5
Food & Beverage	0.4
Clothing & Rubber	1.7
Wood Products	3.0
Paper & Allied	0.8
Primary Metals	0.17
Metal Fabricating	0.05
Transportation	1.3
Non-Metallic Minerals	0.3
Petroleum & Coal Products	0.6
Chemicals & Chemical	1.4

* Computed as a weighted average where weights are total intake.

Canadian manufacturing are twenty-five, fifteen and sixty per cent, respectively). In addition, of the top five water using industries (Primary Metals, Paper, Chemicals, Petroleum and Wood Industries) only Wood and Chemicals have cost shares greater than one per cent. This situation explains why the overall manufacturing average water cost share is only one half of one per cent. There is, however, one source of bias which leads this cost share to be too small. What is reported on the Industrial Water Use Survey are operating and maintenance costs. No capital costs for water use were requested. Thus, Table 5.5 shows the share that the water-related operating and maintenance costs have and not the share for all water-related costs (operating and maintenance plus capital).

D. Summary

What then can be concluded from the data presented in this chapter? The most obvious result is that British Columbia manufacturing industries, on average, spend very little to use large quantities of water. Second, it would appear that their water-related costs are characterized by declining average costs. Both of these conclusions do not bode well for the estimation of water intake demand curves. It remains to be seen whether, despite water expenditures relatively small share of total costs, industrial water demands are sensitive to the average or marginal cost of water intake. These and other empirical issues are the focus of the next chapter.

CHAPTER VI

EMPIRICAL RESULTS

A. Introduction

The purpose of this chapter is to report the results of an estimation of water intake demand equations for British Columbia manufacturing industries. In addition, the water use cost equations, estimated in order to generate price proxies, are reported. Finally the own price and output elasticities of intake water and the cross-price elasticities between water intake and other categories of water use are detailed.

The results reported in this chapter should be interpreted as being preliminary findings. This is because the estimation model chosen (the single equation format) is fairly simple and not rigourously derived from economic principles. In the future more detailed estimation models (with a more firm grounding in economic theory) will be employed.

B. Empirical Results

Most of the firms responding to the Industrial Water Use Survey faced little or no external price for their intake water. As a result some proxy for price must be generated in order to estimate water intake demand equations. In Chapter IV a method, proposed by Ziegler and Bell (1984), was outlined which would generate two proxies for the price of water use in any category: the estimated marginal cost and the estimated average cost.

Table 6.1 represents the results of using the Ziegler and Bell (1984) methodology. For each industry, 'total cost of water use' equations were estimated (using OLS techniques) for four water use categories: intake, treatment, recirculation and discharge. From these regression equations the estimated marginal and average costs of water use were computed and, in turn, used in the demand equation estimation.

The figures reported in Table 6.1 are, for the most part, not very impressive. Many of the estimated equations have quite low levels of explanatory power (seen in the low adjusted R^2 and t ratio values). For the Transportation industry, for example, most of the estimated coefficients are not statistically significant and the F value on the recirculation equation is not high enough to warrant rejecting the null hypothesis that all of the regression coefficients equal zero. In general, the intake cost equation results are best, perhaps reflecting better quality responses by firms. The poor equation results for treatment and recirculation are partially attributable to the large number of survey responses which did not provide this information.

It is rather disappointing that the basis for the construction of the price proxies would be of such a poor quality. In part this is due to the lack of data. In addition, the functional form chosen (ie. the quadratic nature of the total cost equations) is largely arbitrary. It is hoped that future work will yield more

TABLE 6.1

Estimated Water Use Cost Equations
by Industry and Water Use Category[1]
in British Columbia

Food and Beverages

Intake

$$TC = 2284.9 + .56244E{-1}(Q) - .14110E{-7}\ (Q^2)$$
$$(.77896) \quad (5.3157) \quad (-3.5023)$$
$$F = 32.977, \quad R^2a = .3728, \quad DF = 76$$

Treatment

$$TC = 2006.3 + .92908E{-2}(Q) - .21623E{-8}\ (Q^2)$$
$$(2.2397) \quad (2.0054) \quad (-1.5004)$$
$$F = 6.268, \quad R^2a = .0534$$

Recirculation

$$TC = 492.74 + .16767E{-1}(Q) - .10900E{-7}\ (Q^2)$$
$$(1.7055) \quad (5.3105) \quad (-4.8384)$$
$$F = 14.468, \quad R^2a = .2523$$

Discharge

$$TC = 3778.2 + .64932E{-3}(Q) + .36658E{-8}\ (Q^2)$$
$$(1.3879) \quad (.62619) \quad (.96021)$$
$$F = 5.937, \quad R^2a = .0911$$

Clothing, Rubber and Textiles

Intake

$$TC = 2269.8 - .52065E{-1}(Q) + .47640E{-6}\ (Q^2)$$
$$(2.0329) \quad (-1.3511) \quad (2.4469)$$
$$F = 10.287, \quad R^2a = .4585, \quad DF = 16$$

Treatment

$$TC = 18.375 + .18545(Q) - .33962E{-5}\ (Q^2)$$
$$(-.53244) \quad (3.1349) \quad (-2.6568)$$
$$F = 5.249, \quad R^2a = .3336$$

Recirculation

$$TC = -7377.8 + .38208(Q) - .86582E{-9}\ (Q^2)$$
$$(-.50178) \quad (3.5020) \quad (-3.5023)$$
$$F = 4.692, \quad R^2a = .3643$$

Discharge

$$TC = 67.152 - .14743E{-3}(Q) - .14034E{-8}\ (Q^2)$$
$$(.72658) \quad (-.45469) \quad (-.84792)$$
$$F = 3.600, \quad R^2a = .1129$$

Wood Products

Intake

$$TC = 1906.4 + .75613E{-2}(Q) - .60536E{-10}\ (Q^2)$$
$$(.35711) \quad (2.5761) \quad (-1.9196)$$
$$F = 8.686, \quad R^2a = .2049, \quad DF = 23$$

Treatment

$$TC = .15157E{+6} - .93424E{-3}(Q) + .77793E{-11}\ (Q^2)$$
$$(2.7771) \quad (-.43252) \quad (.61503)$$
$$F = 4.956 \quad R^2a = .0633$$

Recirculation

$$TC = 34924 - .68012E{-4}(Q) + .24444E{-13}\ (Q^2)$$
$$(1.4263) \quad (-.13163) \quad (.35454)$$
$$F = 8.570, \quad R^2a = .0802$$

Discharge

$$TC = .13638E{+6} + .12570E{-1}(Q) - .13441E{-9}\ (Q^2)$$
$$(1.1933) \quad (2.0279) \quad (-2.0250)$$
$$F = 7.814, \quad R^2a = .0834$$

Paper and Allied Products

Intake

$$TC = 4234.8 + .47298E{-1}(Q) - .39918E{-8}\ (Q^2)$$
$$(.87909) \quad (6.738) \quad (-5.6288)$$
$$F = 25.622, \quad R^2a = .5197, \quad DF = 51$$

Treatment

$$TC = 2527.0 + .19105E{-2}(Q) - .17229E{-9}\ (Q^2)$$
$$(2.6100) \quad (.92801) \quad (-.87627)$$
$$F = 3.209 \quad R^2a = .0217$$

Recirculation

$$TC = 3614.9 + .33857E{-2}(Q) - .15812E{-9}\ (Q^2)$$
$$(1.9344) \quad (1.7171) \quad (-1.7284)$$
$$F = 3.102, \quad R^2a = .0190$$

Discharge

$$TC = 4663.6 - .21815E{-4}(Q) - .46255E{-10}\ (Q^2)$$
$$(1.8586) \quad (-.56910) \quad (-.11372)$$
$$F = 1.253, \quad R^2a = .0346$$

TABLE 6.1 (Continued)

Transportation Equipment

Intake

TC = 755.48 + .37972E-1(Q) + .56784E-7 (Q^2)
(.33223) (1.2889) (1.2029)
F = 52.688, R^2a = .9037, DF = 9

Treatment

TC = 39.507 - .49035E-1(Q) + .44441E-5 (Q^2)
(.78569) (-3.8297) (20.851)
F = 264.533 R^2a = .9895

Recirculation

TC = 347.10 + .33578E-1(Q) - .22145E-7 (Q^2)
(.19617) (1.9509) (1.7803)
F = 1.935, R^2a = .1587

Discharge

TC = 506.55 - .69817E-1(Q) + .45436E-6 (Q^2)
(.68815) (-.73350) (2.9196)
F = 32.523 R^2a = .8752

Primary Metals

Intake

TC = 51476 + .77884E-3(Q) - .27204E-12 (Q^2)
(1.1981) (.63018) (-.22356)
F = 10.441, R^2a = .7207, DF = 5

Treatment

TC = .50929E-26 +.15563E-6(Q) +.50959E-14(Q^2)
(3.4182) (2.1467) (1.4167)
F = 2.1964 R^2a = .3649

Recirculation

TC = 877.46 - .12837E-3(Q) + .33003E-12 (Q^2)
(.99015) (-.35521) (.34967)
F = 1.327, R^2a = .0377

Discharge

TC = .73643 - .33449E-5(Q) + .32881E-13 (Q^2)
(1.8972) (-2.9851) (2.9802)
F = 33.272 R^2a = .9016

Metal Fabricating

Intake

TC = 1442.2 + .30401E-1(Q) - .26235E-7 (Q^2)
(1.6492) (1.5373) (-1.6276)
F = 5.011, R^2a = .1109, DF = 9

Treatment

TC = .80954E-1 + .51122E-4(Q) - .60929E-9(Q^2)
(.80937) (1.9559) (-1.3321)
F = 9.353 R^2a = .6042

Recirculation

TC = .22016E-2 +.14532E-3(Q) -.46044E-8 (Q^2)
(.14092) (20.632) (-12.884)
F = 451.221, R^2a = .9892

Discharge

TC = .53689E-1 + .46402E-2(Q) -.33809E-8 (Q^2)
(.35322) (1.3171) (-1.0987)
F = 3.573 R^2a = .2563

Non Metallic Minerals

Intake

TC = 3186.7 - .41725E-2(Q) + .98751E-8 (Q^2)
(2.5019) (-.27442) (.62436)
F = 6.067, R^2a = .0171, DF = 29

Treatment

TC = 850.52 - .14312E-2(Q) + .75239E-9 (Q^2)
(1.4420) (-.89260) (.44762)
F = 4.716 R^2a = .0658

Recirculation

TC = .1236.2 + .17611E-1(Q) + .21187E-7 (Q^2)
(.53901) (.73334) (.87300)
F = 11.681, R^2a = .4571

Discharge

TC = 956.72 + .18308E-2(Q) - .37344E-8 (Q^2)
(1.5379) (.16456) (-2.7778)
F = 1.2042 R^2a = .0553

TABLE 6.1 (Continued)

Petroleum Products

Intake

$TC = -30638 + .71700E\text{-}1(Q) - .10956E\text{-}8\ (Q^2)$

(-1.0631) (3.2522) (-2.9800)

$F = 83.080$ $R^2a = .9600$, $DF = 4$

Treatment

$TC = 40789 + .92018E\text{-}2(Q) - .53011E\text{-}10(Q^2)$

(1.6790) (.66370) (-.23270)

$F = 65.811$ $R^2a = .9488$

Recirculation

$TC = .4997 - .54067E\text{-}2(Q) + .39027E\text{-}9\ (Q^2)$

(1.4916) (-1.0844) (3.1781)

$F = 36.702$, $R^2a = .8999$

Discharge

$TC = 17440 + .13264(Q) - .19150E\text{-}8\ (Q^2)$

(.16120) (.87921) (-.75334)

$F = 23.664$ $R^2a = .8883$

Chemicals and Chemical Products

Intake

$TC = 3106.3 + .20411E\text{-}1(Q) - .59948\ (Q^2)$

(.39759) (6.6280) (-4.4550)

$F = 33.429$ $R^2a = .7510$, $DF = 21$

Treatment

$TC = 1917.7 + .15501E\text{-}2(Q) - .24335E\text{-}10\ (Q^2)$

(.80861) (2.2399) (-1.3977)

$F = 5.349$, $R^2a = .2546$

Recirculation

$TC = 7685.7 + .53342E\text{-}2(Q) + .78066E\text{-}9\ (Q^2)$

(1.0970) (.42470) (.46410)

$F = 6.770$, $R^2a = .3385$

Discharge

$TC = -3609.8 + .20382E\text{-}1(Q) - .74708E\text{-}9\ (Q^2)$

(-.34458) (4.9342) (-4.2286)

$F = 10.460$ $R^2a = .5117$

NOTES:

1. Figures in parentheses are t ratios. DF means degrees of freedom for the t ratios. For each estimated equation, TC represents total expenditure reported for that category of water use and Q is the total quantity of water used in that category.

sophisticated methods of generating price proxies (such as using an instrumental variables approach).

Having generated the proxies for water use prices it remains to estimate the water intake demand equations. As discussed in Chapter IV, the demand for water intake was modelled as a function of the price of intake water, the prices of other inputs and the level of output. The 'other inputs' included in our estimation model are other water uses: treatment, recirculation and discharge. The intake demand equation is assumed to be approximated by either equation (7) or (8) in Chapter IV. Preliminary results using the linear dependent variable-logged independent variables form were very poor and, thus, this equation form was abandoned. As a result, three equations for each industry were estimated. These were all of the form of equation (7) in Chapter IV except different price proxies were used in each. The first equation used estimated marginal cost as the price proxy for all four water use categories. The second used estimated average cost for the price of intake and discharge water while using marginal cost for the price of recirculation and treatment. The third equation used the computed average cost to act as price for all water use categories. All equations were estimated with OLS techniques using the econometrics computer package SHAZAM (White, 1978). Once estimated, the three equations (for each industry) were compared and the 'best' equation was chosen for presentation. The choice was made on the basis of the following criteria: equation statistics, significance of coefficients and conformity with expectations regarding the signs of coefficients and elasticity estimates.

Table 6.2 presents the estimated water intake demand equations for the ten British Columbia manufacturing industries under study[1]. All of the equations have the expected negative sign on the own price variable (with the exception of the Clothing industry which has an insignificant coefficient) and a positive sign on the output-proxy variable. On the other hand, for many equations, the coefficients on the price of treatment and price of recirculation variables are not significant - due, perhaps, to the relatively poor quality of the data relating to these variables. The price of treatment variables has a negative coefficient for the Food, Clothing, Pulp, Metal Fabrication, and Petroleum industries (indicating complementarity between intake and treatment) while that coefficient is positive for the rest of the industries (suggesting substitutibility). The price of recirculation variable has a positive coefficient for all industries except Clothing, Metal Fabricating, and Petroleum, suggesting that substitutibility between recirculation and intake is most common. Rather suprisingly only four of the ten equations show the expected negative sign on the price of discharge variable (indicating complementarity). It should be noted, however, that five of the six reported positive coefficients on the price of discharge variable are insignificant at

---

1 Results for the Mining survey are reported in Appendix A.

TABLE 6.2

Estimated Industrial Water Intake Demand Equations[1]

Food and Beverages[2]

$$\ln Q = 10.904 - .48009\,(AC1) - 3.0644\,(MC2) + 3.5869\,(MC3) - .42352E{-1}\,(AC4) + .14458E{-5}\,(THR)$$
$$(3.8667)\quad(-4.7954)\quad(-.82336)\quad(.97424)\quad(-1.5883)\quad(5.1312)$$
$$F = 812.509 \qquad SEE = 1.7039 \qquad R^2a = .4864 \qquad DF = 95$$

Clothing, Rubber and Textiles

$$\ln Q = 14.566 + 76.785\,(MC1) - 6.3622\,(MC2) - 2.0972\,(MC3) + .16558\,(MC4) + .21838E{-5}\,(THR)$$
$$(1.3875)\quad(.74779)\quad(-1.7349)\quad(.95763)\quad(.47725)\quad(.69157)$$
$$F = 163.612 \qquad SEE = 1.5836 \qquad R^2a = .5233 \qquad DF = 24$$

Paper and Allied Products[2]

$$\ln Q = 9.3484 - .17509\,(AC1) - 86.932\,(MC2) + 87.125\,(MC3) - .18446E{-1}\,(AC4) + .10254E{-5}\,(THR)$$
$$(21.915)\quad(-3.6324)\quad(-.38012)\quad(.38096)\quad(-.93462)\quad(3.7690)$$
$$F = 374.488 \qquad SEE = 2.0105 \qquad R^2a = .3958 \qquad DF = 71$$

Wood Products

$$\ln Q = 13.402 - 5.0536\,(ACB1) + 20.978\,(ACB2) + 59.499\,(ACB3) + .45472\,(ACB4) + .47547E{-6}\,(THR)$$
$$(15.145)\quad(-2.8169)\quad(1.4026)\quad(.51966)\quad(1.3383)\quad(3.0977)$$
$$F = 136.018 \qquad SEE = 2.8218 \qquad R^2a = .5027 \qquad DF = 22$$

Primary Metals

$$\ln Q = 8.9801 - .12682\,(ACB1) + .48719E{+6}\,(ACB2) + 38.280\,(ACB3) - 2889.0\,(ACB4) + .30855E{-6}\,(THR)$$
$$(5.9351)\quad(-.26996)\quad(1.4508)\quad(1.0137)\quad(-.27890)\quad(2.8868)$$
$$F = 29.702 \qquad SEE = 2.8020 \qquad R^2a = .6913 \qquad DF = 3$$

Transportation Equipment

$$\ln Q = 10.740 - 7.1411\,(ACB1) + 7.032\,(ACB2) + 27.048\,(ACB3) + 5.6620\,(ACB4) + .19329E{-6}\,(THR)$$
$$(9.3007)\quad(-2.9631)\quad(.31718)\quad(.60184)\quad(.28701)\quad(.70983)$$
$$F = 78.931 \qquad SEE = 1.7185 \qquad R^2a = .5351 \qquad DF = 7$$

Metal Fabricating

$$\ln Q = 7.6426 - .23489\,(ACB1) - 10277.\,(ACB2) - 60783.\,(ACB3) + .53044E + 6\,(ACB4) + .20136E{-5}\,(THR)$$
$$(16.186)\quad(-2.4000)\quad(-1.3522)\quad(-1.5445)\quad(2.20411)\quad(2.9041)$$
$$F = 116.006 \qquad SEE = 1.4525 \qquad R^2a = .6164 \qquad DF = 12$$

Non Metallic Mineral

$$\ln Q = 12.325 - .15513\,(AC1) + 2136.0\,(MC2) + 31.894\,(MC3) - .18568\,(AC4) + .50680E{-6}\,(THR)$$
$$(8.3766)\quad(-3.2559)\quad(2.4855)\quad(1.2614)\quad(-2.5645)\quad(1.4165)$$
$$F = 360.894 \qquad SEE = 1.4935 \qquad R^2a = .5279 \qquad DF = 45$$

TABLE 6.2 (Continued)

Petroleum Products

$$\ln Q = 15.001 - 60.732\,(ACB1) - 36.497\,(ACB2) - 8.5602\,(ACB3) + 6.8689\,(ACB4) + .12706E\text{-}5(THR)$$

(6.2775) (-6.8190) (-.85816) (-2.8140) (.51402) (.84631)

F = 47.131 SEE = 2.2806 R^2a = .6850 DF = 1

Chemicals and Chemical Products

$$\ln Q = 5.5145 - .10544\,(AC_1) + 1122.3\,(MC_2) + 258.10\,(MC_3) + .15577E\text{-}1\,(AC_4) + .90620E\text{-}5(THR)$$

(1.8762) (-2.4537) (.66794) (1.3639) (1.0177) (4.5409)

F = 177.657 SEE = 1.9652 R^2a = .6708 DF = 34

NOTES:

1. For each industry, three equations were estimated (see the text for further discussion) and the 'best' equation (in terms of statistical significance) is reported here. Figures in parentheses are t ratios. The following is a list of variable definitions:

   Q = quantity of intake water
   MC1 = estimated marginal cost of intake
   AC1 = estimated average cost of intake
   ACB1 = computed average cost of intake
   MC2 = estimated marginal cost of treatment
   ACB2 = computed average cost of treatment
   MC3 = estimated marginal cost of recirculation
   ACB3 = computed average cost of recirculation
   MC4 = estimated marginal cost of discharge
   AC4 = estimated average cost of discharge
   ACB4 = computed average cost of discharge
   THR = total employee hours

   All of the estimated equations are of the logged dependent variable - linear independent variables form. Reported below each equation are the estimation statistics: F ratio (to test the hypothesis that all estimated coefficients are not statistically different from zero), standard error of the estimate (SEE), adjusted R^2 and the degrees of freedom for the t ratios (DF).

2. All equations were tested for homogeneity of degree zero in prices (i.e. that the coefficients on the price variables sum to zero). Only the equations for Food and Pulp failed the test. These were then reestimated with homogeneity imposed as a restriction.

the .05 per cent level. Further discussion of the relationships between intake and other water uses is delayed until the estimated elasticities are presented in Table 6.3.

It is interesting to note that each of the three equation forms appears at least once. The form using computed average cost was chosen most often (five times), while the equation using estimated average cost was chosen four times. The equation using estimated marginal cost as the price proxy was chosen only once. Thus, when the two forms of average cost proxies are taken together, it is seen from Table 6.2 that the average cost proxy appears to provide superior explanatory power than the marginal cost proxy in nine cases out of ten.

All of the equations have relatively good statistics considering the quality of the responses and the cross-sectional nature of the data set. Adjusted R^2 values range from 0.39 (Pulp) to 0.69 (Primary Metals). This suggests that the demand equation models are able to explain between forty and seventy per cent of the variation of water use, depending on the industry. In addition, all equations have high F ratio values, implying rejection of the null hypothesis that the estimated coefficients in any equation are all zero. Each equation was tested for homogeneity of degree zero in prices. This was done by testing whether the sum of the price variables' coefficients equalled zero. All equations except Food and Pulp passed the test. These equations were then reestimated with the homogeneity restriction imposed. It is the restricted version for those two industries which is reported in Table 6.2.

As indicated in Chapter IV, one of the most important economic statistics generated by applied work is the price elasticity. By concentrating on elasticities one can make comparisons across industries which are free of bias introduced by differences in scale or units of measurement. Table 6.3 presents estimates of elasticities (computed at the mean of the data in each case) from the regression equations presented in Table 6.2.

Table 6.3 presents the own price and output elasticities of water intake (E_{II} and E_{IO}, respectively) and the cross-price elasticities of intake water with respect to treatment, recirculation and discharge (E_{IT}, E_{IR} and E_{ID}, respectively). All of the own price elasticities are negative while only Petroleum, Clothing, and Transportation are greater than one (in absolute value). Interestingly, the 'big four' water users (Chemicals, Primary Metals, Pulp and Petroleum) have quite inelastic intake demands, with only Petroleum having an elasticity greater than a half. This indicates that the 'big four' water users have intake demands which are not very sensitive to changes in water's price.

The cross-price elasticities show no general patterns. Five industries indicate substitutibility between intake and treatment and five show complementarity. This is also true for the

TABLE 6.3

Industrial Water Demands in British Columbia:
Estimated Price and Output Elasticities[1]

Industry		Estimated Elasticity	Industry		Estimated Elasticity
Food & Beverages	E_{II}	-0.35108	Primary Metals	E_{II}	-0.011698
	E_{IT}	-19.830		E_{IT}	0.57415
	E_{IR}	-0.65304		E_{IR}	0.34545
	E_{ID}	-0.85645E-1		E_{ID}	-0.10890
	E_{IO}	0.36706		E_{IO}	1.9563
Clothing, Rubber, Textiles	E_{II}	-1.5401	Transportation	E_{II}	-1.2134
	E_{IT}	0.2479		E_{IT}	0.19195
	E_{IR}	-0.74773		E_{IR}	0.17647
	E_{ID}	-3.9709		E_{ID}	0.20538
	E_{IO}	0.33229		E_{IO}	0.63852E-1
Paper & Allied Products	E_{II}	-0.38536	Metal Fabricating	E_{II}	-0.23356
	E_{IT}	-2.8119		E_{IT}	-0.26202
	E_{IR}	-1.1593		E_{IR}	-0.82756
	E_{ID}	-0.81358E-1		E_{ID}	-1.0222
	E_{IO}	0.34517		E_{IO}	1.4784
Wood Products	E_{II}	-0.78170	Non Metallic Minerals	E_{II}	-0.25277
	E_{IT}	0.35960		E_{IT}	-2.92782
	E_{IR}	0.10624		E_{IR}	0.66507
	E_{ID}	0.19560		E_{ID}	-0.35181
	E_{IO}	1.6487		E_{IO}	0.13606
Petroleum	E_{II}	-1.7937	Chemicals & Chemical Products	E_{II}	-0.29466
	E_{IT}	-1.5794		E_{IT}	1.6175
	E_{IR}	-0.33963		E_{IR}	1.1726
	E_{ID}	-0.99891		E_{ID}	-0.13401
	E_{IO}	2.3529		E_{IO}	1.8586

NOTES:

1. For each industry, this table reports five estimated elasticities (computed from the regression coefficients reported in Table 6.2) calculated at the means of the data set. The following elasticities are reported:
   - E_{II} = the own price elasticity of intake water
   - E_{IR} = the cross price elasticity of intake water and recirculation
   - E_{IT} = the cross price elasticity of intake water and treatment
   - E_{ID} = the cross price elasticity of intake water and discharge
   - E_{IO} = the output elasticity of intake water.

   All of these terms are defined in Chapter IV of this report.

relationship between recirculation and intake. The latter observation is somewhat suprising as it was expected most industries would exhibit an ability to substitute recirculation for water intake. If some of the major water users (for example, Pulp and Petroleum) view recirculation and intake as complements rather than substitutes then some other methods will have to be found to encourage decreased water use other than increased reliance on recirculation.

Most industries display complementarity between discharge and intake, as was expected. This seemingly straightforward relationship, however, may be complicated by some firms' use of intake water to dilute wastewater concentrations. This might be done if sewer charges were a function not only of quantity of wastewater but also the concentration of wastes (cf. Sims, 1981).

The own output elasticities are very interesting. All output elasticities are positive and some are quite large (indeed, for the 'big four' water using group the average output elasticity is approximately 1.6). This particular set of results is not reassuring; it would indicate that future growth in manufacturing will imply substantial increases in demands for intake water.

C. Summary

This chapter has presented the results of the first round of estimation of water intake demands for British Columbia manufacturing industries. There is ample evidence of the price responsiveness of intake water and for the possibility of substituting among intake, recirculation and treatment in some industries. There is also, however, evidence of the limitations that recirculation faces as a solution to the water shortage problem. This is an important and potentially troublesome finding; as is the average magnitude of output elasticities among the 'big four' water users.

It merits repeating that these results should be viewed as being preliminary. More sophisticated econometric methods are feasible and could be used in future studies. It is also possible to formulate a model which considers the demand for water as part of a system of interrelated demand equations. The optimal levels of intake, treatment, recirculation and discharge could then be estimated simultaneously for the British Columbia manufacturing industry in order to get an understanding of the interrelationships between water use and other inputs. An important concern in these types of studies would be the definition and generation of price variables.

CHAPTER VII

INDUSTRIAL VALUATION OF WATER

A. Introduction

British Columbia manufacturing industries use very large amounts of water each year. But a question which needs answering is, what value does each industry put on its water intake? More importantly in theory, or in practice, can what a firm or an industry is willing to pay for water be measured?[1] It turns out that the answer is a tentative 'yes'. Economic theory provides the framework within which the industrial valuation of water may be estimated and the data available from the Industrial Water Use Survey allows initial estimates to be generated.

B. Industrial Valuation of Water: Theory

How highly Canadian manufacturing firms value their use of water is largely an unexplored issue. However, as the possibility of future regional water shortages increases, the relative valuation of water by all industries will become more and more relevant. If society is to derive the maximal benefits from the use of water available to it, an important consideration in the apportionment of scarce water supplies will be the estimated relative value of competing users.

---

1 To an economist, the value of a commodity is approximated by determining the maximum amount that individuals (or firms) would be willing to pay for the right to use it.

In addition, in order to evaluate a proposed water-related public works (a storage dam, for example) it is often necessary to have an estimate for how much users will value an increase in reliable water supply. A further issue which requires an understanding of the valuation of water use is the question of domestic water transfers and water exports. Presumably, any decision on whether to export water will depend, inter alia, on a comparison of the benefits derived from the water which is being considered for export if it remains in Canada and whatever compensation Canada is to receive for the exported water. The former will be based in part on the expressed valuations of current water users. But how are these valuations to be estimated?

In Chapter 2 some of the alternative methods of computing industrial willingness to pay for water were outlined (herein the phrase 'willingness to pay' will be replaced by WTP). In that chapter the best economic proxy of the firm's WTP for an additional unit of any input was identified to be that input's contribution to the firm's profits. In this section that assertion will be justified and the 'mechanics' of estimating industrial WTP for water will be discussed.

How much should a firm pay for a unit of water? Suppose the firm knew that using one more cubic metre of water would add one dollar to its total profits. Then, a firm should not pay more than one dollar for that unit of water for if it did it would be decreasing its total profit. On the other hand if the firm pays less than one dollar it will be adding to its total profits. However, if the firm is paying, for example, eighty cents for its last unit of water and earning a dollar of profit (assuming all other factors of production are paid their opportunity cost price) is it doing the best it can? No, it is not. The firm could increase profits by expanding its water use until the price it pays just equals its incremental contribution to profits. Only then will the firm be in equilibrium with respect to water use.

Economists usually assume that firms undertake something like the decision making outlined in the previous paragraph. As a result they can state that the maximum amount a firm should be willing to pay is the value in dollar terms of an input's incremental contribution to profit.

The actual amount a firm is willing to pay for an input can be surmised by referring to the firm's demand curve for that input. For any quantity of the input, the height of the demand curve (holding the quantities of all other inputs constant) gives the per unit gross WTP. If the demand curve is integrated (i.e. find the area under the demand curve) then an estimate of the total gross WTP for that quantity of input is derived. Finally if the per unit WTP and the price actually paid for the input is compared then the difference represents the net contribution to profits or the net per unit WTP. Of course, for the equilibrium quantity of the input (i.e. where the supply curve intersects the demand curve for that input) the gross per unit WTP is just equal to the price charged and, as a result, per unit net WTP is equal to zero. If all the per unit net WTP generated by the use of an input can be added up[2] then an estimate of total net benefit occurring to the firm through use of that input is available.

C. Industrial Valuation of Water: Evidence

The previous section discussed the economic theory behind the valuation of industrial water use. This section reports this study's estimates of the valuation by British Columbia manufacturing industries of water intake.

Table 7.1 presents gross and net willingness to pay figures for the ten British Columbia industrial groups. The methods employed to obtain these estimates are described in notes to the Table. There are several interesting features contained in this Table. First, if the gross WTP figures are compared to the total intake expenditures reported in Table 5.2 then it can be seen that the estimated gross WTP is greater than reported intake expenditures for all industries except the Pulp and Paper industry. Second, note that the average net WTP are all substantially less than the average gross WTP. Only in the cases of the Pulp and Chemicals industries are the average net WTP greater than ten per cent of the average gross WTP. Third,

---

2 This requires integrating the area under the demand curve but above the equilibrium price (for a single equilibrium price) or the area between the demand and supply curves (for a block-rate pricing structure).

TABLE 7.1

Industrial Water Demands in British Columbia:
Estimated Gross and Net Willingness to Pay

	Total Gross[1] WTP (million$)	Average Gross[1] WTP ($/m^3)	Total Net[3] WTP (million$)	Average Net[4] WTP ($/m^3)
	- 1981 dollars -			
Food & Beverages	89.503	2.583	1.648	0.0476
Clothing, Rubber and Textiles[5]	-	-	-	-
Wood Products	107.944	1.735	1.021	0.0164
Paper & Allied Products	0.156	0.009	0.046	0.002
Primary Metals	50.944	0.045	0.999	0.0009
Metal Fabricating	4.219	1.776	0.036	0.023
Transportation Equipment	0.911	0.585	0.009	0.004
Non Metallic Minerals	11.197	2.184	0.158	0.031
Petroleum Products	132.369	2.001	0.110	0.017
Chemicals & Chemical Products	20.535	0.255	2.754	0.034

NOTES:

1. Computed as the area beneath the industry water intake demand curve for quantities less than the estimated equilibrium water intake quantity.

2. Obtained by dividing total gross WTP by total water intake.

3. Computed as the area between the industry water intake demand curve and the estimated water supply-price curve for quantities less than the estimated equilibrium water intake quantity.

4. Obtained in the same manner as average gross WTP.

5. Not calculated because of the poor quality of the estimated water intake demand curve.

there is a significant diversity in the average net willingness to pay. Not surprisingly the Food and Beverage industry has the highest per unit net valuation and the Primary Metals industry (the province's largest water user) has the lowest.

The results reported in Table 7.1 may be compared to the only other reported source of industrial water valuation figures. Using figures from the Young and Gray study (1972), Muller (1985) reports the following average net WTP for various industries (these valuations were assumed to be the same across Canada): Food and Beverage, \$123.65 /1000m^3; Chemical Products, \$75.92 /1000m^3; and Pulp and Paper, \$86.74 /1000m^3. All the values are expressed in 1984 dollars. Even after allowing for inflation (i.e. this study's dollar figures are 1981 dollars while Muller's are expressed in 1984 dollars) all the estimated WTP for British Columbia's manufacturing industries are less than those reported by Muller[3] - although the two estimates for the Petroleum industry are quite close this study's estimate is \$17.00 /1000m^3 (1981 dollars) while Muller's is \$18.55 /1000m^3 (1984 dollars).

---

3 There is a reason why this study's WTP estimates are lower than Muller's. The Muller estimates are not really WTP values but are engineering estimates of the cost of recirculating water in each industry (these estimates are computed in the Young and Gray (1972) study). The logic in using the cost of recirculation as a proxy for WTP is that recirculation is often the closest substitute to increased intake. However a more complete modeling of each industry's technology - one which allows for the substitution of labour or capital for intake water, for example - is necessary to determine what is indeed the lowest cost substitute for intake water. The present study considers a slightly more general model of water use than did Grey and Young (1972) and, as a result, has estimated lower WTP values because it considers a wider range of possible substitutes to intake water.

Much more work is needed on the topic of industrial valuation of water use. The results presented here, if indicative of the benefits derived from industrial water use throughout Canada, suggest that very little net benefit accrues to manufacturing industries (and, in turn, to Canadian society) from water use[4]. This is almost certainly related to the fact that since most industrial water users face negligible external prices for their intake water, they have expanded their water use (thereby substituting away from relatively more expensive labour and capital inputs) to the point where little net benefit is earned from their water withdrawals. Future studies would provide new (and hopefully improved) parameter estimates with which more accurate industrial valuation estimates could be generated.

---

4 It is possible that the method of estimated demand equations biases the WTP estimates to underestimate the true industrial valuation of water. Demand curves were estimated using observations primarily drawn from large water users. As a result the estimated demand curves may appear 'flatter' than they would if more observations of small water using firms were used. If the estimated demand curves are, indeed, too flat for small quantities of water intake then industrial WTP could be underestimated.

CHAPTER IIX

CONCLUSIONS

Industrial water demands have not received much study. Those studies which have been conducted, however, indicate that industrial water demand is price sensitive. As well, there are important and not well understood interactions between firms' water use and their use of other productive inputs. Yet, the value of the past research on industrial water demands is diminished because they are all based on the use of highly aggregated data sets of American industrial water users.

The jurisdictional background surrounding the withdrawl of freshwater in British Columbia is fairly clear. Under the Canadian Constitution, British Columbia has almost exclusive authority over the regulation of the use of freshwater resources within its boundaries. It carries out these responsibilities primarily through the Water Act which allows the provincial government to set rental fees to be paid by people or companies wishing to withdraw water for private use. Alternatively, those firms relying on a public utility or municipal agency to supply their intake water, must pay a price (often computed from complicated block rate tariff structures) for their water. The data set used in this study is comprised primarily of British Columbia firms' responses to Environment Canada's 1981 Industrial Water Use Survey. This survey questioned nearly four thousand companies throughout Canada on their quantities and costs of water intake, treatment, recirculation and discharge. Some missing cost of intake observations were replaced with estimates based on the rental tariffs for water withdrawal specified under the Water Act.

Economic theory specifies a model of the factors affecting a representative firm's demand for water. This model emphasizes the prices of water and other inputs and the level of the firm's output as explanatory factors. Once a general model of intake water demand (which relates the quantity of water used to the price of water and other factors) has been developed, then a statistical model must be specified in order to estimate empirically the structure of water demands. The estimation of demand equations is not straightforward, however, due to the problems of defining the price of water. If the marginal cost of water intake depends on the quantity consumed then the estimation of demand equations is faced with a simultaneity problem. This could result in potentially biased estimates in the sense that the reported average of the estimated parameter may not equal the true unknown population mean. While this econometric problem remains unresolved a method for generating several price variables was suggested and the format of the demand equations was presented in Chapter IV.

The costs of water use to British Columbia manufacturing firms are strikingly small. One way to see this is by considering the cost of water use as a fraction of the total costs of a firm or industry. In British Columbia estimates of this sort range from 0.05 per cent for the Metal Fabricating industry to 3.0 per cent for the Wood products industry. Thus, water costs are a very small portion of most British Columbia firms' costs.

The estimated water intake demand equations were reported for ten manufacturing industry groups in Chapter VI. These equations showed price responsiveness in all industries with intake price elasticities ranging from -0.01 (Primary Metals) to -1.7 (Petroleum). As well, intake demands were shown to be sensitive to output levels and that there existed possibly strong interactions between water intake and other industrial water uses. An important result was that, in general, the 'big four' water users exhibited relatively low price elasticities and high output elasticities. These results are potentially important both from a regulatory and from a water use forecasting point of view.

The industrial valuation of water use is a largely unexplored issue in Canada. The estimated industrial willingness to pay figures (the economist's approximation to the value of water) were strikingly low using the British Columbia manufacturing data. In Chapter VII, it was reported that average gross willingness to pay (in 1981 dollars) ranged from \$9 /1000 m^3 (Pulp) to \$2580 /1000 m^3 (Food) while average net willingness to pay figures were much lower: \$0.9 /1000 m^3 (Primary Metals) to \$48 /1000 m^3 (Food). These estimates are substantially below comparable figures reported by Muller (1985).

This study has explored a very recently developed field. Industrial water demands have received little or no attention from researchers in Canada. There still exist several areas where unresolved methodological questions persist (especially in the construction of a 'price of water' variable). While the results reported here must be interpreted with caution it is hoped that they may contribute to a better understanding of the pressures being placed upon British Columbia's freshwater resources.

There are several feasible extensions to this project. In terms of the methodology employed a more sophisticated treatment of price variables including perhaps an instrumental variables approach could be investigated. In addition, it is possible to model industrial water demands as part of a system of interrelated input demands. This more general modeling should provide more robust estimates of own and cross price elasticities. Finally, these more general modeling techniques may be applied to the entire Canadian data set rather than restricting attention to the British Columbia data. This extension would allow regional differences in industrial water demands to be identified.

APPENDIX A

MINING WATER DEMANDS

A. Introduction

The major concern of this study has been to model the water demands of the manufacturing industry. This appendix overviews efforts to model the water demands of British Columbia mining industry[1]. While this industry's annual water use (124 million cubic metres in 1981) is small relative to the entire manufacturing sector's water use (2181 million cubic metres), its water withdrawal rate is surpassed only by two manufacturing industries - Primary Metals and Paper products.

The analysis developed in the main body of this report is applied to a data set for the British Columbia mining industry. This data set is drawn from the 1981 Mining Water Use Survey conducted by Environment Canada and is augmented (where cost of water intake was not reported) with provincial water rental records. In total the sample consists of twenty-seven observations on individual mines and their respective water uses and expenditures.

---

1 Unfortunately, data limitations did not allow a dissaggregation beyond the 'mining industry' level.

B. Water Use in the Mining Sector

Of the major water using sectors, mining is the smallest in British Columbia[2]. Yet the mining industry's use of water is important for several reasons. First, the size of individual mines implies that they may be very important when water use studies are disaggregated to a specific river basin. For example, coal developments represent a potentially significant portion of water withdrawals in the Flathead River basin in southeastern British Columbia. A second reason is that mining ranks only behind agriculture in consumption of its intake water. The 1981 Canada Water Yearbook reports that in 1980 the British Columbia mining sector consumed approximately 40 per cent of its water withdrawals (Table 3, p. 24). Finally, the quality of discharge water from minesites can be a serious environmental concern. Elevated acidity levels and increased levels of suspended solids and heavy metals can often be characteristics of mines' runoff water.

Table A.1 summarizes the various aspects of the mining industry's water use. The 'total water use' part of Table A.1 is quite interesting. The mining industry apparently practices substantial water recirculation. Yet the discharge figure exceeds the intake figure. This may be due to the fact that many mines and oil and gas fields contain significant amounts of groundwater which must be

---

2 The 1981 Canada Water Year Book reports the following annual withdrawal figures (in millions of litres per day):

Municipal and Rural	1076	Manufacturing	5642
Mining	277	Agriculture	1568
Thermal	787		

TABLE A.1

Summary of British Columbia Mining Water Use Statistics

Total Water Use (million m^3)

Intake	124.39
Treatment	30.29
Recirculation	350.01
Discharge	139.17

Breakdown of Intake by Purpose[1] (million m^3)

Processing	106.81
Cooling and Condensing	11.67
Sanitary	5.77
Other	0.13

Breakdown of Intake by Source[2] (million m^3)

Public		4.54
Private:	Surface	65.47
	Ground	16.91
	Other	37.45

Breakdown of Discharge by Point of Discharge[3] (million m^3)

Public		0.009
Private:	Freshwater body	28.89
	Tidewater body	23.85
	Ground	16.59
	Tailings Pond	69.83

Mining Water Use Relative to Employment and Output

Total Intake	124.39	(million m^3)
Total Value of Output[4]	2499.455	(million 1981$)
Total Employment[5]	11648	
Ratio: Intake/Employee	10.679	(1000 m^3/person)
Ratio: Intake/Value of Output	0.0497	(m^3/1981$)

NOTES:

1. Source: Tate and Scharf (1984), Vol II, Table 2.08
2. Source: ibid, Table 2.11
3. Source: ibid, Table 2.20
4. Source: Statistics Canada (1981), SC26-201
5. Source: ibid

pumped out. The majority of water intake is used for process as Table A.1 indicates. This is in contrast to the manufacturing industry's water use which was concentrated in cooling and steam production. The mining industry resembles the manufacturing industry, however in that it also has an almost total reliance on privately supplied water and it uses private discharge points. However, the mining industry makes a proportionately larger use of tide water bodies for intake and discharge.

Finally, Table A.1 reports mining water use relative to employment and mining output. The mining ratio of water intake to employee is low relative to the manufacturing industry as is mining's ratio of water intake to dollar value of output.

C. Empirical Results

In order to study the mining industry's water demands the same procedures used in studying of the manufacturing sector were used. Thus, the same techniques were used to determine water use costs, to construct water prices, to estimate water intake demand equations and to estimate mining industry's valuation of water use. The results of the work are summarized in Table A.2.

Water use costs are not a significant factor for the mining industry in British Columbia. In fact they are almost negligible - the estimated cost share for water use is only 0.25 per cent. As well,

TABLE A.2

Water Use by British Columbia's Mining Sector:
Summary of Mining Empirical Results

Costs of Water Use

Purpose	Total Cost (million 1981$)	Computed Average Cost[1] (1981$/1000$m^3$)	Estimated Marginal Cost[2] (1981$/1000$m^3$)
Intake	1.9208	45.59	20.26
Treatment	0.2957	372.19	7.96
Recirculation	2.7785	138.99	5.99
Discharge	2.0097	145.77	7.63
Total			

Estimated Cost Share[3]

Ratio: Total Water Costs to Total Operating Costs 0.26%

Estimated Cost Equation[4]

Intake

$$TC = 13765 + 0.28061E\text{-}1(Q) - 0.86447E\text{-}9\,(Q^2) \quad F = 10.157 \quad R^2_a = .3025$$
(.50823) (3.4395) (-3.1759) DF = 21

Recirculation

$$TC = 72704 + 0.70434E\text{-}2(Q) - 0.51861E\text{-}10\,(Q^2) \quad F = 3.987 \quad R^2_a = .0303$$
(1.4323) (1.5147) (-1.6336)

Treatment

$$TC = 8974.5 + 0.10054E\text{-}1(Q) - .11359E\text{-}8\,(Q^2) \quad F = 2.876 \quad R^2_a = .0299$$
(1.0891) (1.0017) (-1.0462)

Discharge

$$TC = 28937 + 0.31919E\text{-}2(Q) + 0.40463E\text{-}9\,(Q^2) \quad F = 5.540 \quad R^2_a = .2747$$
(.5596) (.21033) (.74370)

TABLE A.2 (Continued)

Estimated Intake Demand Equation and Elasticities[5]

$$\ln Q = \underset{(26.485)}{15.154} - \underset{(-4.6723)}{6.0501}(AC1) - \underset{(-2.7107)}{128.70}(MC2) - \underset{(-.46954)}{48.775}(MC3) + \underset{(3.7430)}{2.2742}(AC4) + \underset{(2.4459)}{0.15277E\text{-}6}\,(THR)$$

$$F = 626.745,\quad SEE = 1.1795,\quad R^2{}_a = .7847,\quad DF = 21$$

$$E_{II} = -2.4171,\quad E_{IT} = -.96471,\quad E_{IR} = 0.27796,\quad E_{IO} = -1.6818,\quad E_{IQ} = 0.55793$$

Valuation of Water Use[6]

	Total (million$)	Average 1981$/1000m^3)
Gross Willingness to Pay	54.657	439.40
Net Willingness to Pay	1.028	8.27

NOTES:

1. Defined as Total Cost divided by Total Quantity
2. See Table 5.4 and the preceding discussion for definition
3. See Table 5.5 and the preceding discussion for definition
4. See Table 6.1 for definition of variables
5. See Tables 6.2 and 6.3 for definitions of variables
6. See Table 7.1 and the preceding discussion for definitions

the reported average and marginal cost estimates are fairly low relative to those seen in Tables 5.3 and 5.4. The estimated cost equations serve the same purpose and carry the same interpretation as those reported for the manufacturing industries in Chapter VI.

The estimated water intake demand equation and the relevant price and output elasticities are also reported in Table A.2. With respect to the estimated demand equation it can be seen that both the price and output coefficients are of the expected sign and are significant. In addition, the own price elasticity (E_{II}) is rather high at -2.4. The other elasticities indicate substitution possibilities between intake and recirculation and complementarity between treatment and intake and between discharge and intake.

The last entry in Table A.2 presents estimates of the mining industry's valuation of its water use. The method used to construct these estimates is detailed in Chapter VII. Both the gross and net willingness to pay estimates are low relative to the figures reported in Chapter VII for the manufacturing industry. This is not very surprising when one recognizes that most water used in the mining industry either breaks or carries unprocessed ore.

This appendix has presented the results of this study's findings of the British Columbia mining industry's water demands. It was seen that the mining industry was a relatively small user of water from a provincial perspective but a large user when one considered consumption rates or when one adopted a regional point of view. Water intake demand was found to be quite sensitive to the average cost of intake despite the relative insignificance of water costs. As well, estimated valuation (either gross or net) of water use by the mining industry was quite low on average.

APPENDIX B

1976 BRITISH COLUMBIA INDUSTRIAL WATER DEMANDS

A. Introduction

As part of a National Industrial Water Use Survey conducted by the Inland Waters Directorate, Environment Canada, in 1976, a large number of British Columbia firms were surveyed regarding the quantities and costs of their water use. In 1984, the British Columbia survey results formed the basis for a statistical study of industrial water demands conducted by the staff of Inland Waters Directorate, Pacific and Yukon Region.[1] That study (herein referred to as the BWM study), perhaps the first of its kind in Canada, was particularly concerned with testing the hypothesis that industrial water demands were insensitive to price changes (cf. DeRooy, 1974). The BWM study estimated water intake demand price elasticities ranging from -0.432 (the Beverage industry) to -1.186 (the Petroleum Refining industry).

The purpose of this appendix is to report on the re-estimation of 1976 industrial water demand equations. There are two reasons why this re-estimation was conducted. First, after the BWM study was completed it became possible to augment the data set by inputing water intake costs to non-respondents. This was done by using water price rates obtained from municipalities in which non-respondent

---

1 This study was undertaken by M. Betkowski, I. Wells and R. McNeill during the summer of 1984.

firms were located (British Columbia Water and Waste Association, 1979 and 1982). In total twelve non-zero responses were added, representing a 7.5 per cent in usable observations. The second cause for re-estimation concerned the estimation methodology used by BWM. In that study, the price of water intake was proxied by the average of reported operating and maintenance costs of water intake. As outlined in the main body of this report, using average cost as a proxy for price can lead to simultaneity in demand equation estimates and, thus, lead to biased parameter estimates. As an alternative the price proxy was generated using the Ziegler and Bell (1984) method (discussed in Chapter IV). The rest of this essay concerns itself with a brief discussion of the estimation method and reporting and interpreting the results of the re-estimation. The industries considered are listed in Table B.1.

TABLE B.1

Industry Groupings in BWM Study

Industry	SIC (1980)
Chemicals	37
Refining	36
Concrete Products	354
Transportation	30
Wood Products	27
Pulp and Paper	25
Foodstuffs	10
Beverages	109
Fruit Processing	103
Mining[1]	06

NOTE: 1. This industry was not included in the present study because of a loss of the data set.

B. Estimation Procedure

Under the assumption of cost minimizing behaviour, economic theory indicates that the general form of a firm's (or, under conditions sufficient for aggregation, an industry's) derived demand function for water should resemble:

$$(1)\quad Q_w = f(P_w, X, P_1, \ldots P_n, T).$$

Where:

Q_w = the quantity of water demanded
P_w = the price of water
X = the level of firm (or industry) output
$P_1 \ldots P_n$ = the prices of all non-water inputs
T = an index of technological progress.

In order to estimate equation (1) must do several things must be done. First a functional form must be specified. The log-linear and linear-log forms are used. The specification of the model's variables must be determined. The quantity of water intake demanded is measured in thousands of gallons per year. The proxy for price of water was constructed as follows (cf. Ziegler and Bell, 1984). First, the following equation was estimated for each industry using OLS techniques:

$$(2)\quad TC_w = a_0 + a_1 Q_w + a_2 (Q_w)^2 + e$$

Where:

TC_w = total operating and maintenance costs of water intake
Q_w = total quantity of water intake
a_0, a_1,
a_2 = parameters to be estimated
e = error term, assumed to have with a normal distribution with zero mean and constant variance.

From equation (2), estimates of the marginal and average costs (equations (3) and (4), below) were obtained and used as proxies for the price of water:

$$(3) \quad MC_w = a_1 + 2 \cdot a_2 \cdot Q_w$$

$$(4) \quad AC_w = a_0/Q_w + a_1 + a_2 \cdot Q_w$$

A simple average cost was also computed by dividing total intake expenditures by total water intake. Thus, we have three potential proxies for the price of intake water. Each shall be used in the estimation of intake demand functions and their respective explanatory power will be considered.

Unfortunately, the level of the firm's output was not elicited by the survey. As a proxy for output total-employee-hours per year have been used. There are obvious problems with this procedure. Total employee hours will act as a good proxy for output if it is highly correlated with output and if the demand for labour is separable from the demand for water intake. Regrettably, there is no way to test this last assumption.

The coding of the 1976 survey did not include the questions relating to the costs of other water-related inputs. As a result, it was not possible to include the prices of other inputs in the estimation of the water intake demand equations.

In the absence of data regarding the prices of non-water intake inputs and regarding the technological character of each observation, several dummy variables were used. Our use and definition of these variables coincides with the BWM study. Table B.2 gives a description of how the dummy variables were used for each industry grouping.

TABLE B.2

Dummy Variables Used in Estimation Models

Industry Group	Dummary Variable[1] Public[2]	Treat.[3]	Recirc.[4]	D4[5]
Transportation	X			X
Foodstuffs	X	X		
Pulp & Paper	X	X		
Wood Products	X	X	X	
Beverages	X	X	X	X
Refining	X	X	X	X
Concrete	X	X	X	X
Chemicals	X	X	X	X
Fruit Processing	X	X		X

NOTES:

1. A cross (X) indicates the inclusion of that dummy variable in the estimation of that industry's demand equation.

2. Public = 1 if the observation drew water from a public utility
   = 0 otherwise

3. Treat = 1 if the observation treated intake water prior to use
   = 0 otherwise

4. Recirc.= 1 if the observation recirculated water in the production process
   = 0 otherwise

5. D4 is an industry specific variable. The following breakdown gives its definition, by industry:

Transportation	D4=1	if observation is a shipbuilding firm
	=0	otherwise
Beverages	D4=1	if observation produced alcoholic beverages
	=0	otherwise
Concrete	D4=1	if observation both treated and recirculated water
	=0	otherwise
Chemicals	same definition as Concrete	
Fruit Processing	D4=1	if observation produced fruit juice
	=0	otherwise
Refining	D4=1	if observation was on oil refinery
	=0	otherwise

Thus, the industry water intake demand equation estimated was one of the two following forms:

$$(5) \quad \log Q_w = a_0 + a_1 P_w + a_2 THR + a_3 D + u$$

$$(6) \quad Q_w = b_0 + b_1 \log P_w + b_2 \log THR + b_3 \log D + v$$

where D = vector of dummy variables

THR = total employee hours

u, v are error terms, assumed to have a normal distribution with mean zero and constant variance.

C. Empirical Results

All of the estimation was conducted using OLS techniques on the econometrics computer program, SHAZAM (White, 1978). Observations reporting zero costs of intake were deleted if an expenditure on water intake could not be imputed through reference to the respondent's municipal water works' rate tables. It is acknowledged that the deletion of zero cost observations is not without risk. It is possible that some firms do, indeed, have minimal water intake costs; however, the estimation of demand equations does require non-zero price observations. It was felt that the empirical results based on skipping the zero cost observations would provide a better picture of industrial water demands in British Columbia.

The first set of results concerns the costs of water intake. Table B.3 reports the industry averages for three categories of

TABLE B.3

Water Intake Costs ($\$/m^3$)

Industry Group	Computed Mean Average Cost[1]	Estimated Mean Average Cost[2]	Estimated Mean Marginal Cost[3]
	- 1976 dollars -		
Chemicals	0.204	9.776	0.004
Refining	0.808	5.311	*[4]
Concrete	0.772	1.358	*[4]
Transportation	0.811	1.179	0.218
Wood Products	1.135	3.332	0.362
Pulp and Paper	0.479	1.603	0.393
Foodstuffs	0.299	1.079	0.231
Beverages	0.561	0.432	0.257
Fruit Processing	0.221	0.407	0.274

NOTES:

1. Computed Average Cost = Total Cost of Water Intake divided by Total Quantity of Water Intake.
2. From equation (2).
3. From equation (2).
4. * indicates an estimate less than zero.

intake cost: computed average cost (found by simply dividing total costs of intake by total quantity of water intake), estimated average costs and estimated marginal costs (the latter two categories are derived from estimations of equation (2) for each industry). The striking thing about Table B.3 is the magnitude of the estimated mean marginal costs. No industry has a mean marginal cost greater than forty cents per cubic metre of water.

It is difficult to tell, however, whether the reported average intake costs are 'high' or 'low' simply by studying Table B.3. We may use a 1979 survey of British Columbia municipal water rates (BCWWA, 1979) to evaluate the figures reported in Table B.3. From that survey (cf. Table 4.3) it can be calculated that the average annual charge for a commercial-industrial metered user was approximately \$4,000 /1000m^3/year (1979 dollars). If an adjustment for inflation is made this annual average cost is about \$2,800 /1000m^3/year (1976 dollars). This figure is more than twice the highest reported annual average intake cost (the wood products industry reports \$1,135 /1000m^3/year (1979 dollars). It would appear that a major reason why the annual average intake costs reported in Table 3 appear low is that the majority of these firms are self-supplied[2] and 'pay' for their water only through licence and rental fees to the provincial government and through in-house

2 According to Tate (1976), more than 94% of B.C. industrial water intake was self-supplied.

expenditures on the operation and maintenance of their water intake systems.

Table B.4 presents the estimates of water intake price elasticities by industry which were computed by BWM and the present study. The BWM study's estimates are generally lower than those computed from the re-estimated industrial intake water demand equations. However, both studies find substantial evidence of price responsiveness. These results are important for two reasons. First, they cast doubt upon the 'fixed coefficient' method of water use forecasting commonly employed today. It would seem that inclusion of price elasticities in these models would in general lower demand forecasts and this, in turn, may avert the unnecessary expansion of water supply capacity. Secondly, these results give credence to those who have called for an enhanced role for demand-side management to water use problems (cf. Tate, 1984). If industrial water intake demands are price sensitive, as they have been demonstrated here, then the price of water is a potentially important variable to be considered in the balancing of supply-demand projections.

The final set of results are summarized in Table B.5. These are the coefficient estimates of the industrial intake water demand equations. Note for each industry, the functional form and price proxy used are reported. These were chosen as the 'best' equations based on the equation statistics (R^2 adjusted, F value, SEE, individual t values). It is interesting to note that the estimated

TABLE B.4

Comparison of Water Intake Price Elasticities

Industry	BWM Study	Renzetti Study
Chemicals	-0.849	-0.911
Refining	-1.186	-0.673
Concrete Products	-0.110	-0.576
Transportation	-[1]	-1.103
Wood Products	-1.136	-1.024
Pulp and Paper	-0.256	-1.003
Foodstuffs	1.0453	-1.325
Beverages	-0.043	-0.534
Fruit Processing	-[1]	-1.1027
Mining	-0.408	-[2]
Heavy Manufacturing	0.052	-[2]

NOTES:

1. Not reported in BWM Study.
2. These industries were not included in the current study because the data were unavailable.

TABLE B.5

Estimated Demand Equations

Industry Group	Functional Form: Equation[3]	Functional Form: Price Proxy[1]	Coefficient Estimates[2]: Constant	Price	Thr	Pub	Treat	Recr.	D4	Equation statistics: R^2 adjusted	F	SEE	Elasticities: Price	Output	Degree of Freedo
Chemicals	loglin	ACE	7.3638 (1.1160)	-.9323E-3 (-0.6791)	.5773E-3 (.2944)	.7315 (.3976)	3.5640 (1.5096)	.12503 (.02386)	.62406 (.29254)	.7547	76.805	1.8239	-.91130	1.5062	7
Refining	loglin	ACE	9.3536* (4.9383)	-.12684* (-3.9584)	.10925E-2 (1.3299)	-1.4513 (-1.6767)	2.4944** (2.8809)	.37709 (.43531)	-.91864 (-.96550)	.7822	185.813	1.4238	-.67357	2.5204	14
Concrete	linlog	ACE	.1750E+6 (1.4919)	-.16573* (-5.7571)	-.22537 (-1.4613)	-2029.1 (-.3506)	.15014E+6* (10.191)	806.07 (1.0997)	.11381E+6* (7.2450)	.9459	101.303	1.4753	-.57561	-.78276	22
Trans-portation	loglin	ACE	10.608* (5.9290)	-.93504** (-2.8462)	.49842E-3 (.6665)	-3.4726* (-3.2136)	.87226 (1.2751)	---	---	.7529	226.136	.92369	-1.1027	.90640	11
Wood	loglin	ACE	2.3272 (0.9534)	-.30718* (-3.0680)	.20640E-2 (2.2137)	-.75647 (-.83624)	1.5984 (2.1161)	1.3959 (1.3027)	---	.7028	105.767	1.2661	-1.0235	4.1981	11
Pulp	loglin	ACE	1.5734 (0.1411)	-.58418* (-3.1495)	.30474E-2 (2.5433)	-.58991 (.88031)	-.34582 (-.48772)	---	---	.4077	88.832	1.4515	-1.0032	5.4632	15
Foodstuffs	loglin	ACE	10.0649* (8.4791)	-3.7500* (-5.3883)	.22401E-3 (.47253)	-.20494 (-.35661)	1.0782* (2.4138)	---	---	.6120	472.038	1.1543	-1.3249	.45816	28
Beverage	loglin	ACC	10.727* (4.7135)	-.69228 (-2.0168)	.12525E-2 (.95368)	-4.0274 (-2.0811)	.49745 (.39630)	.81763 (.90040)	---	.3596	119.633	1.5663	-.53388	2.3504	13
Fruit	loglin	MCE	7.1683 (0.88125)	-3.4452 (-.18140)	.26005E-3 (.46773)	.16189 (.08780)	-.42360 (-.28016)	.67340 (.94014)	2.8626 (2.6296)	.7911	178.746	.8471	-.94362	1.0730	7

NOTES:

1. ACE = estimated average cost (equation 4); MCE = estimated marginal cost (equation 3); ACC = computed average cost
2. The numbers in parentheses ore t values; * denotes significance at .005 level, ** denotes significance at .01 level
3. Loglin refers to the form of equation (5), linlog refers to equation (6)

average cost happens to be the 'most popular' proxy for intake price - being chosen seven out of nine times. It is possible that the mean marginal cost of water intake was typically so small for most industries that it did not play a significant role in decision making. Instead, firms concerned themselves with the average cost of water intake. If this is indeed the case then the criticism levelled against declining block rates for encouraging excessive consumption may not be as strong as previously supposed. This is certainly a matter which warrants further research.

With regard to the coefficient estimates, the results would seem quite plausible. All of the price proxies have negative coefficients and most are significant. With the exception of the concrete products industry, all the output proxy coefficents are positive although most are statistically insignificant. Most of the coefficients on the public water supply dummy variable have a negative sign - indicating perhaps that the prevalence of metered charges for public water acts as a disincentive to water intake and thus lowers the demand for water. Most of the coefficients on the water treatment dummy variable are positive, suggesting a direct correlation between intake and treatment. Rather suprisingly, the coefficients on the recirculation dummy are positive (although not significant). While this particular result mirrors the BWM study, it was expected that water intake and water recirculation were substitutes. The paucity of cost-of-recirculation data in the reported surveys may be a factor but the relationship between water intake and recirculation merits further investigation.

When the equation statistics are examined it would seem that the functional forms and price proxies chosen provide quite good explanatory power. This is particularly true considering that the estimation was based on cross-sectional data. For all equations, the F statistic is high enough to ensure rejection of the null hypothesis (that all the coefficients equal zero) at the .01 level.

Finally, note should be made of the reported elasticities. The price elasticities are repeated from Table B.4 and need no further discussion. The 'output elasticities' must be interpreted with care. If the proxy employed for output (total employee hours) does not misrepresent the relationship between water intake and the firms output, then the results are quite interesting. The output elasticity figures suggest that, for unchanged prices and using current technology, future growth in these industries will be water intensive in nature. With the exception of the transportation goods, food and concrete products industries, a one per cent growth in output for any industry will lead to at least a one per cent growth in water intake. The weakness with which technological change can be modelled using cross-sectional data, however, casts some doubt on these output elasticity estimates.

The empirical results of this re-estimation are quite interesting. They indicate industrial water intake demands are sensitive to the price or cost of water intake and that other water uses influence intake. The results, however, suggest several potentially valuable avenues for future research.

D. Summary

The purpose of this appendix was to document the efforts to re-estimate water intake demand equations using 1976 data for the British Columbia Manufacturing sector. The results summarized here suggest that water intake demands are sensitive to the price or per unit cost of intake water and to the level of output. The revised intake demand equations also tentatively indicate that per unit cost may be a more important economic variable to firm managers than the marginal cost in planning water use.

Research into the economic characteristics of industrial water use in Canada is woefully inadequate. Next to nothing is known regarding industrial valuation of intake water or whether technological progress has been water-using or water-saving. These topics, and others mentioned throughout this report, certainly merit further research.

REFERENCES

Al-Quanaibet, M. and R. Johnston (1985) "Municipal Demand for Water in Kuwait: Methodological Issues and Empirical Results", WRR, 21(4), April, 433-438.

Alberta Environment, Planning Division, Planning Services Branch (1983), Alberta Industrial Water Use Survey 1981, Edmonton.

Anderson, R. and J. Thursby, (1985) "Confidence Intervals for Elasticity Estimators in Translog Models", Ohio State University Department of Economics Working Paper 85-11, June.

Andrews, A. and K. Gibb (1975) "An analysis of the effect of price on residential water demand: Metropolitan Miami", Southern Journal of Agricultural Economics, 7(1), 125-130.

Babin, F., C. Willis and P. Allen (1982), "Estimation of Substitution Possibilities between Water and other Production Inputs", American Journal of Agricultural Economics, 64(1), 148-51.

Berndt, E. (1976), "Reconciling Alternative Estimates of the Elasticity of Substitution", Review of Economic and Statistics, 58(1), 59-68.

Berndt, E. and D. Wood (1975), "Technology, Prices and the Derived Demand for Energy", R.E. Stat., 56(3), 259-68.

Berndt, E. and L. Christensen (1973), "The Translog Production Function and the Substitution of Equipment, Structures and Labour in U.S. Manufacturing, 1929-1968", Journal of Econometrics, 1(2), 81-114.

Billings, R. (1982), "Specification of Block Rate Price Variables in Demand Models", Land Economics, 58(3), 386-394.

Billings, R. and D. Agthe (1980), "Price Elasticities for Water: A Case of Increasing Block Rates", Land Economics, 56(1), 73-84.

Billings, R., and D. Agthe (1981), "Price Elasticities of Water: A Case of Increasing Block Rates: Reply", Land Economics, 57(2), 276-278.

Bowden, G. (1985) "Water and Canadian Agriculture: Selected Issues", Research Report 18 for the Inquiry on Federal Water Policy, Environment Canada.

British Columbia Water and Waste Association (1979), Survey of Municipal Water and Sewer Rates for British Columbia, Vancouver.

British Columbia Water and Waste Association (1982), Survey of Municipal Water and Sewer Rates for British Columbia, Vancouver.

Brown, G., and B. Field (1979), "The Adequacy of Measures for Signalling the Scarcity of Natural Resources", in V. Smith, ed., Scarcity and Growth Reconsidered, Resources for the Future, Baltimore.

Brown, G.M. and R. Johnson, (1983), "Pollution Control by Effluent Charges: It works in the Federal Republic of Germany, Why not in the U.S.", NRJ, 24(4), October 929-967.

Burgess, D. (1974), "Production Theory and the Derived Demand for Imports", Journal of International Economics, 4, 103-117.

Burgess, D. (1975), "Duality Theory and Pitfalls in the Specification of Technology", Journal of Econometrics, 3, 105-121.

Carver, P. and J. Boland (1980), "Short and Long Run Effects of Price on Municipal Water Use", Water Resources Research, 20(1), 609-616.

Christensen, L., D. Jorgenson and L. Lau (1973), "Transcendental Logarithmic Production Frontiers", R.E. Stat., 55(1), 28-45.

DeRooy, J. (1974), "Price Responsiveness of the Industrial Demand for Water", Water Resources Research, 10(3), 403-406.

Diewert, W.E. (1975) "Applications of Duality Theory", in M. Intrilligator and D. Kendricks (eds.) Frontiers of Quantitative Economics, VII, Amsterdam: North-Holland 106-71.

Erxleben, J. and E. Hoyes (1983), "Industrial Water Allocation and Utilization in Alberta", Canadian Water Resources Journal, 8(4), 20-35.

Field, B., and C. Grebenstein (1979), "Substituting for Water Inputs in U.S. Manufacturing", WRR, 15(2), 228-232.

Field, B., and C. Grebenstein (1980), "Capital - Energy Substitution in U.S. Manufacturing", R.E. Stat., 62(2), 207-212.

Fisher, A. (1979), "Measures of Natural Resource Scarcity", in V. Smith, ed., Scarcity and Growth Reconsidered, op. cit., 249-271.

Fortin, M. (1985), "User Pay Pricing in the Canadian Municipal Water Industry", Research Report 10 for the Inquiry on Federal Water Policy, Environment Canada, Ottawa.

Foster, H., and B. Beattie (1979), "Urban Residential Demand for Water in the United States", Land Economics, 55(1), 43-59.

Foster, H., and B. Beattie (1981), "On the Specification of Price in Studies of Consumer Demand under Block Price Scheduling", Land Economics, 57(4), 624-629.

Foster, H., and D. Sewell (1981), Water: The Emerging Crisis in Canada, Canadian Institute for Economic Policy, Toronto.

Fuss, M. (1979), "The Demand for Energy in Canadian Manufacturing", Journal of Econometrics, 5(1), 89-116.

Gardner Pinfold Consulting Economists Ltd. (1983), "A Study of Water in the Economy of Atlantic Canada", Report prepared for Inland Waters Directorate, Atlantic Region, Environment Canada, Halifax.

Gilchrist, D. (1983), "Property Rights and Water Scarcity: A Selective Overview", CWRJ, 8(4), 88-99.

Gray, S., and R. Young (1972), The Economic Value of Water: Concepts and Empirical Estimates, Report to the U.S. National Water Commission, Washington, D.C.

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

Griffith, F. (1984), "Peak Use Charge: An Equitable Approach to Charging for and/or Reducing Summer Peak Use", CWRJ, 9(3), 17-22.

Grima, A. (1972) Residential Water Demand, Alternative Choices for Management, University of Toronto Press, Toronto.

Grima, A. (1984), "Empirical Basis for Municipal Water Rates Modification", CWRJ, 9(3), 23-40.

Hanke, S. (1978) "A Method for Integrating Engineering and Economic Planning", JAWWA, 70(9), 487-92.

Hanke, S. and L. de Mare. (1982) "Residential water demand: A pooled, time series, cross section study of Malmo, Sweden", Water Resources Bullentin, 18(4), 621-625.

Hanke, S. and M. Fortin (1985) "The Economics of Municipal Water Supply: Applying the User-Pay Principal", Research Report 21 for the Inquiry on Federal Water Policy, Environment Canada, Ottawa.

Hanke, S., and L. de Mare (1984), "Municipal Water Demands", in J. Kindler and C. Russell, eds., Modeling Water Demands, Academic Press, London.

Hare, K. (1985), "The Impact of Human Activities on Water in Canada", Research Report 2 for the Inquiry on Federal Water Policy, Environment Canada, Ottawa.

Herrington, P. (1985), "Pricing of Water Services", draft report for the Steering Group on the Economic Aspects of Water Conservation, Environmental Committee of the Group of Economic Experts, OECD.

Hill, I., B. McClennon and D. Tate (1983), "Macroscale Modeling of Water Demand with Emphasis on the Energy Sector", CWRJ, 8(4), 67-87.

Howe, C. and F. Linaweaver (1967) "The impact of price on residential water demand and its relation to system design and price structure", WRR, 3(1), 13-32.

Humphrey, D., and D. Moroney (1975), "Substitution of Capital, Labour and Natural Resource Products in American Manufacturing", Journal of Political Economy, 83(1), 57-82.

Jones, C., and J. Morris (1984), "Instrumental Price Estimates and Residential Water Demand", WRR, 20(2), 197-202.

Kindler, J., and C. Russell (1984), "Methodological Framework", in Kindler and Russell eds., Modelling Water Demands, op. cit.

Kulshreshtha, S. (1983), "Water Demand in Saskatchewan: Implications for Industrial Development", CWRJ, 8(4), 42-57.

London, R. (1984), "Region of Durham Experiences in Pricing and Water Conservation", CWRJ, 9(4), 19-28.

Maddala, G. (1977), Econometrics, McGraw-Hill, New York.

Millerd, F. (1984), "The Role of Pricing in Managing the Demand for Water", CWRJ, 9(4), 7-17.

Mitchell, B. (1984), "The Value of Water as a Commodity", CWRJ, 9(2), 30-38.

Moore, C. (1984) "UBC NLE: Zeros of Nonlinear Equations", University of British Columbia Computing Centre, Vancouver.

Muller, R. (1985), "The Socio-Economic Value of Water in Canada", Research Report 5 to the Inquiry on Federal Water Policy, Environment Canada, Ottawa.

Nicol, T. (1984) "Integration Routines", mimeo, University of British Columbia Computing Centre, Vancouver.

Nordin, J. (1976), "A Proposed Modification of Taylor's Demand Analysis: Comment", Bell Journal of Economics, 7 (Autumn), 719-721.

Pearse, P. (1985) Currents of Change, Final Report of the Inquiry on Federal Water Policy, Environment Canada, Ottawa.

Rao, P., and R. Preston, (1983), Interfactor Substitution and Total Factor Productivity Growth: Evidence from Canadian Industries, Economic Council of Canada discussion paper 242, Ottawa.

Rueggeberg, H. and A. Thompson (1984) "Water Law in Canada", Research Report 1 for the Inquiry on Federal Water Policy, Environment Canada, Ottawa.

Russell, R. and M. Wilkinson (1979) Microeconomics, John Wiley and Sons, New York.

Sewell, R. and L. Roueche (1974) "Peak load pricing and urban water management: Victoria, B.C., a case study", Natural Resources Journal, 14(3), 383-400.

Sigurdson, D. (1982) "Consumer Surplus from Public Water Works", Canadian Journal of Agricultural Economics, 30(2), 359-368.

Statistics Canada, Manufacturing Industries of Canada: national and provincial areas, (SC 31-203, annual), various issues.

Statistics Canada, Manufacturing Industries of Canada: sub-provincial areas, (SC 31-209, annual), various issues.

Statistics Canada, Private and Public Investment in Canada: Mid Year Review, (SC 61-206, annual) various issues.

Stone, J., and D. Whittington (1984), "Industrial Water Demands", in Modeling Water Demands, op. cit., 51-101.

Tate, D. (1983), "Water Use in the Canadian Manufacturing Industry, 1976", Social Sciences Series 18, Inland Waters Directorate, Environment Canada, Ottawa.

Tate, D. (1984), "Canadian Water Management: A One-Armed Giant", CWRJ, 9(3), 1-7.

Tate, D., P. Reynolds and P. Dossett (1984), "The Role of Water Pricing in Canadian Water Management", mimeo, Inland Waters Directorate, Environment Canada, Ottawa.

Tate, D., and D. Scharf (1985), "1981 Industrial Water Use Survey Tables: Volume I - Water Use in Manufacturing", Inland Waters Directorate, Environment Canada, Ottawa.

Tate, D., and D. Scharf (1985), "1981 Industrial Water Use Survey Tables: Volume II - Water Use in Mineral Extraction, Thermal Power and Hydro Power", Inland Waters Directorate, Environment Canada, Ottawa.

Taylor, L. (1975), "The Demand for Electricity: A Survey", Bell Journal of Economics, 6 (Spring), 74-110.

Terza, J., and W. Welch (1982), "Estimating Demand Under Block Rates: Electricity and Water", Land Economics, 57(4), 624-629.

Thrall, R.M., et. al. eds. (1976) Economic Modeling for Water Policy Evaluation, Amsterdam, North Holland Publishing.

White, K. (1978), "A General Computer Program for Econometric Methods - SHAZAM", Econometrica, 46(1), 239-240.

Ziegler, J., and S. Bell (1984), "Estimating Demand for Intake Water by Self-Supplied Firms", WRR, 20(1), 4-8.