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SIGNATURE

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AN ANALYSIS OF RESIDENTIAL WATER DEMAND FOR ONTARIO AND THE PRAIRIE PROVINCES FROM 1989 TO 1999

By

Andréanne Boisvert

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Abstract

The research centred on the factors accounting for variations within residential water demand. To accomplish this task, the statistical technique of regression analysis was used to analyze water demand data compiled by Environment Canada, for five different years, within two Canadian regions: Ontario and the Prairie Provinces. Two dependent variables were analyzed: total residential water demand (TRWD) and residential water demand per capita (RWD/cap).

Within the TRWD model, population served by water services was found to be the only statistically significant variable, with coefficients of determination around 0.9. It was therefore found, that for forecasting of regional water demands, multiplying a predicted population level with a per capita coefficient might be a sufficient technique at the regional level. Other variables tested included price structure, price of water services, household income and rainfall.

With respect to the RWD/cap model, marginal prices were found to be statistically significant within the Prairie region, as well as for the combination of both regions. Price elasticity values averaged –0.2 for Ontario and –0.3 for the Prairies. These values are consistent with other elasticity values found in previous work in different regions throughout the world. The rainfall variable was also found to be statistically significant. These two variables were therefore analyzed in a multiple linear regression model. Price structure was also tested on the entire dataset, and found to be the variable that had the highest coefficients of determination (R^2), and was consistently significant throughout the regions. Other variables tested included density, and household income.

The latter were found to be insignificant statistically in explaining the variance in RWD/cap.

The multiple linear regression model produced R^2 values that were very low (varying from 0.030 to 0.130). The independent variables clearly did not account for a large proportion of total variance in RWD/cap. Accordingly, there was a large degree of randomness in the datasets. These low coefficients of determination were fairly unexpected, because previous research by other investigators in various regional contexts had shown that the selected independent variables produced higher coefficients of determination. One of the possible reasons for obtaining such low coefficients was the low water prices within the region of study. Since these prices were so low, consumers did not react to changes as the water bills account for such a small portion of the water budgets. Possible reasons for this finding are discussed near the end of this thesis.

Résumé

La recherche se concentre sur les facteurs qui expliquent les variations de la demande en eau résidentielle. La régression linéaire a été utilisée pour analyser les données de la demande en eau compilées par Environnement Canada, pour cinq années différentes, et considérant deux régions canadiennes: l'Ontario et les Prairies. Deux variables dépendantes ont été analysées soit la demande totale en eau résidentielle (DTER) et la demande en eau résidentielle par habitant (DER/hab).

Parmi le modèle de DTER, la population municipale desservie par les services d'eau a été la seule variable à être statistiquement significative, avec des coefficients de détermination de l'ordre de 0.9. Ainsi, la multiplication de population estimée par une valeur de demande d'eau par habitant serait suffisant pour la prédiction des demandes d'eau à l'échelle régionale. Parmi les variables testées pour ce modèle, nous retrouvons la structure de prix, le prix pour les services d'eau, le revenu par maisonnée moyen et les précipitations.

En ce qui concerne le modèle de DER/hab, il a été démontré que les prix marginaux étaient statistiquement significatifs au sein de la région des Prairies, ainsi que parmi les bases de données combinées pour les deux régions. Les valeurs d'élasticité de prix étaient, de –0.2 pour l'Ontario et de –0.3 pour les Prairies, en moyenne. Ces valeurs sont parallèles avec celles retrouvées à travers les différentes régions du monde. La variable de précipitation a aussi été statistiquement significative avec, par contre, certaines exceptions. Ces deux variables ont été, conséquemment, analysées dans un modèle de régression linéaire multiple. La variable de structure de prix a également été statistiquement significative, alors qu'elle a été testée sur la base de données entière.

Cette variable s'est avérée la plus homogène, en étant statistiquement significative à travers les deux régions et toutes les années à l'étude. La structure de prix s'est vue comme la variable possédant les coefficients de détermination (R^2) les plus élevés. Les autres variables testées incluent la densité de la population et le revenu par maisonnée moyen.

L'analyse de régression multiple a produit des valeurs de R^2 qui étaient très basses (variant de 0.030 à 0.130). Les variables indépendantes, n'expliquent pas la majorité des variations dans la DER/hab. Ainsi, les bases de données peuvent être caractérisées par un degré élevé de désordre. Ces basses valeurs de coefficients de détermination sont quelque peu singulières, car la recherche scientifique précédente, parmi des contextes régionaux différents, suggérait que les variables indépendantes choisies produisent des coefficients de détermination plus élevés. Une explication possible à ces basses valeurs est le prix modique des services d'eau résidentielle dans la région à l'étude. Comme ces prix sont bas, les consommateurs ne réagissent pas aux changements de prix, car le coût total est une portion minime du budget d'une maisonnée. Une discussion de ces résultats se retrouve vers la fin de cette thèse.

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CHAPTER I

Water: A Fundamental Municipal Resource

1.1 Introduction

Supplying potable water is one of the most fundamental responsibilities of all municipalities. Households, businesses, industries, and institutions all rely on water of high quality and adequate quantity. Municipal water supplies are crucial to the development of a regional economy. The tradition of providing centralized municipal water services is a well-established one in Canada. For example, between 1961 and 1978, the Canada Mortgage and Housing Corporation provided approximately 2 billion dollars in loans for about 4,500 Canadian municipal water system upgrading projects, as well as $750 million in grants for some 6,100 water projects (Bircham and Bond, 1984). In addition, a portion of federal regional economic expansion funding was spent on basic municipal water supply and sewage treatment servicing. These are but two examples that indicate the importance of reliable water servicing in the support of viable municipalities.

The types and quantities of demands placed on water systems largely condition the task of supplying water. Accordingly, studying the nature of the demands for municipal water provides a valuable perspective on supplying municipal water services. The last two decades of research in Canadian environmental management have been characterized by the search for new approaches to traditional problems. One of these fields of research focuses on water demand management. For the purposes of this thesis water demand management is defined as any socially beneficial action that reduces or reschedules the demand for water from either surface or ground sources, consistent with maintaining adequate water quality (Tate, 1990). Research has shown that economic factors play an important role within this field, for example, it has been shown that water pricing have an influence of water demand levels (Brooks and Peters, 1988; Environment Canada, 1987; Renzetti, 1999).

1.2 Background

Many of the management techniques and disciplines applied to natural resources, that are traded in organized, competitive markets, remain largely unused in the area of water management. For example, it has been shown that natural resources that are traded in these types of markets seldom become scarce (Barnett and Morse, 1963). In fact, historical data show that goods traded in competitive situations become more plentiful over time (Simon, 1981). Marketed resource commodities like crude petroleum and various minerals are relatively impervious to scarcity because of the incentives that competitive economic markets create.

The dynamics of this incentive phenomenon are interesting and fundamental. The "actors" involved in natural resource decision-making may be divided into two basic categories: suppliers and demanders. Suppliers of a resource service are motivated to supply their respective resource at the lowest possible cost and are motivated to search for new sources of currently used resources or for appropriate substitutes. Demanders, on the other hand, are interested in satisfying their needs at the lowest possible cost. These two sets of forces meet in what are called competitive markets; the interaction results in not only resources being supplied at competitive prices, but also, and more importantly, in technological innovation. This "dynamic" is important in dealing with all types of resources including environmental resources like water, air and land (Pearse and Tate, 1991).

Resources like air and water do not fall into the category of marketed resource material, goods and services, largely because they are not traded in competitive markets and are considered to be public goods (Tietenberg, 1996). These environmental resources are assumed to be free goods, and are often over-used and degraded as demand for them grows, fundamentally because there are few effective controls on demand levels. One example of such control would be full-cost pricing. Although prices are charged for water services, charges relate only to the costs of water servicing and usually only a portion of these. In other words, water per se is most often very cheap, or even free.

Despite the fact that water does not trade in competitive markets, instruments such as effective pricing arrangements have been found to be important influences on water demand levels. For example, many authors in the past (Renzetti, 1999; Grima, 1972; Howe and Linaweaver, 1967) have found that water prices are important in explaining the volumes of water demanded by individual water consumers. This finding alone suggests that socio-economic factors are important in determining water demand levels.

It is well established that Canada's residential water prices are among the lowest of the world (OECD, 1999). Also, Canada's per capita water-use rates are among the highest in the world. Generally, these low Canadian water prices have resulted in substantial government subsidies for water infrastructure with a clear emphasis on developing capital works for water supply and waste treatment. The basic reason for this need has been the failure of local governments to raise sufficient funding for adequate water service provision. This heavy emphasis on public subsidies, as well as extremely cheap water prices, has resulted in an over-capitalized water infrastructure, an overuse of water and the need for expanded waste treatment systems. For several reasons, the funds required to maintain and enhance this infrastructure are no longer being transferred from senior levels of government. Realistic water pricing, with a focus on full-cost recovery has been suggested as an economic instrument that can offer a solution to this funding problem (Environment Canada, 1987). In a sense, the use of water pricing could pay "double dividend" in that demand levels can be reduced at the same time as revenues can be generated (Terkla, 1984). This thesis explores some of the issues raised in this section.

1.3 Purpose of the Research

The purpose of this research is to examine the factors that underlie residential water demand. The reason for undertaking this task is to understand residential water demand in order to use this knowledge in decision-making for municipal infrastructure planning. Although there are many factors, which may underlie the demand of residential water, this research is particularly interested in some of the socio-economic factors involved. If socio-economic measures are to be accepted as legitimate instruments for influencing water policy, as suggested by Pearse *et al.* (1985), an essential step is to understand these determinants and relationships. In this context it is important to note that two geographic perspectives have been used to study in the area of municipal and residential water demand: an intra-municipal level which focuses on water use within individual municipalities; and inter-municipal studies compare data across a set of individual municipalities. This is important because the types of variables that are of importance to each of these studies may vary significantly. This issue will be addressed specifically in section 1.7.

1.4 Scope of Study

This research focuses on an analysis of the residential portions of the municipal water use and water pricing surveys carried out by Environment Canada over the period of 1989 to 1999, and includes five complete sets of data (1989, 1991, 1994, 1996, 1999). These databases comprise two separate sets of data: the Municipal Water Use Database (MUD) and the Municipal Water Pricing Database (MUP) (Environment Canada, 1999a, 1999b).

The study covers two major Canadian regions: the province of Ontario and the Prairies (Manitoba, Saskatchewan, and Alberta). This selection of regions has a dual purpose. The first purpose is to undertake a comparison between regions with different physical characteristics, particularly with regard to precipitation, a potentially important influence on demand levels. The second purpose is to obtain adequate and approximately equivalent sample sizes of the databases between the two regions. Approximately 250 municipalities are found within the databases for the Prairie Provinces and 300 for Ontario (Figure 1).

The research was carried out in two phases. First, patterns of variations within the dependent and independent variables were analysed statistically using a set of descriptive statistics for each individual year and for each region. Research carried out in the past (Howe and Linaweaver, 1967; Foster and Beattie, 1979) has suggested that there are significant differences in water use patterns between humid and semi-arid areas. Research to clarify these differences has not yet been carried out for Canada.

Second, regression analyses were run using a pooled cross-section set of data, to try to determine systematic variation in the data, using the regression models to be outlined in Chapter 3. The reasons for using a pooled cross-section are principally to increase the number of observations in the analysis, thereby making the results more robust, and to generate regression parameters that apply across a multi-year period of record.

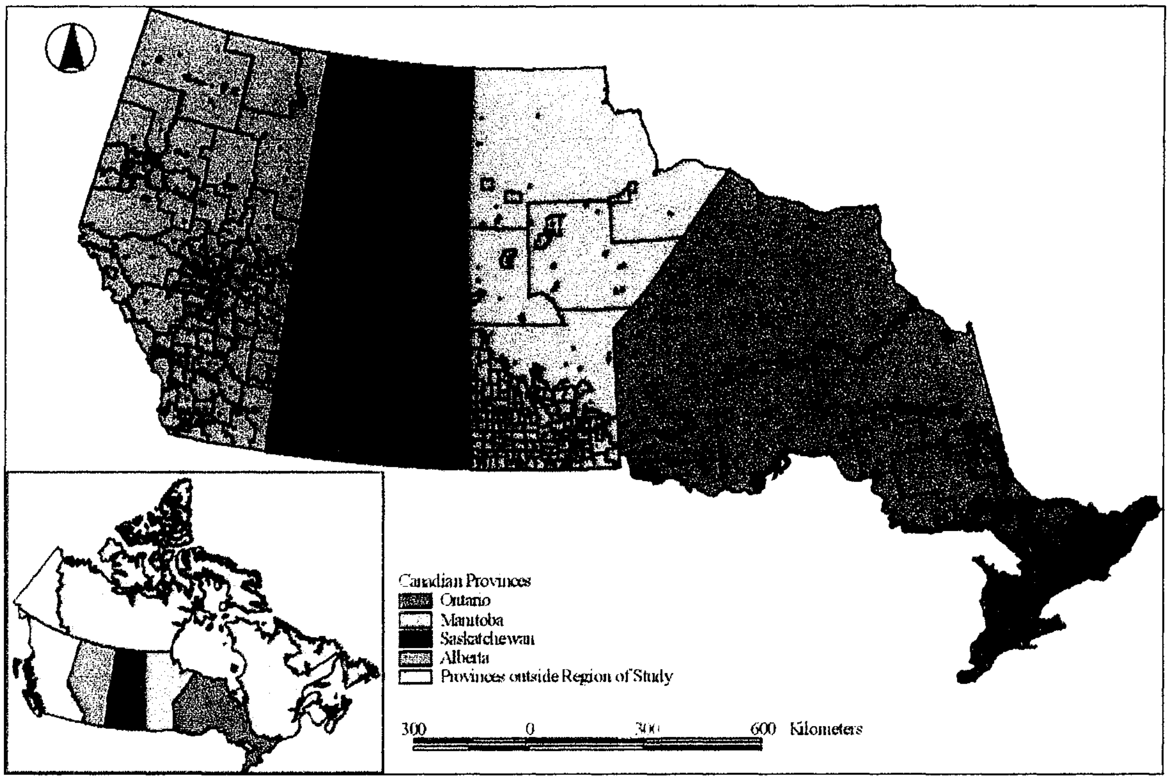

Figure 1: Municipal Boundaries for Provinces within Region of Study

1.5 Structure of the Thesis

The remainder of this chapter discusses the relevance of this research to the field of geography and presents the limitations of the study. Chapter 2 presents a review of the academic and professional literature relevant to the thesis subject. Both Canadian and international studies will be included. This review will also serve to define the key terminology to be used throughout the thesis. Chapter 3 uses the findings of Chapter 2 to define the methodology in the research. This chapter includes: an outline of the data gathering procedures from the surveys; definitions of key variables; transformations required to some of these variables; and techniques used to combine the variables from the multiple databases. It then explains the steps used in carrying out the data analysis, as well as the justification for additional transformations to some of the original variables.

Chapter 4 presents the results of the research. It begins by presenting a series of descriptive statistics outlining the major trends and relationships for important factors, such as survey response rates, variations of total and per capita water demand, proportions of water supply sources, pricing structure ratios as well as general price statistics. This discussion is followed by the presentation of the results obtained using the two residential water demand models as outlined in Chapter 3. The fundamental purpose here is to discuss the results obtained from the two models used in the analysis. Chapter 5 discusses the implications of these results.

Finally, Chapter 6 presents the conclusions of this empirical study and the implications of the findings for water management in the Canadian context. This chapter closes by some outlining future research needs in the residential water demand field.

1.6 Geographical Context of Research

The research concerns the human use of an important environmental resource. This leaves little doubt that the study of water demand is an appropriate field for geographical research, as shown by Sewell and Roueche (1974) and Mitchell (1979). In particular, Mitchell (1979) indicated that the scope of geographical research includes the compilation of resource inventories and knowledge of current and future resource demands within water management.

Traditionally, municipal water management has most frequently been approached from a largely physical viewpoint. For example, a main interest has been on supplying water for municipal purposes regardless of demand levels. Demand has been considered largely as a requirement which must be met, rather than a variable which can be influenced by several different factors. Typically, engineers have centred their research on water supply management issues. Although a water supply management orientation to the study of water resources is a legitimate one, this orientation can be enhanced significantly with the addition of social science considerations. In other words, the addition of techniques adopted from the social sciences can augment traditional approaches to the overall benefit of society.

Water demand management, as defined earlier, involves studying the allocation and demand for water resources. The general purpose of this field is to ensure that the water needs are met presently and that appropriate measures can be put into place to guarantee that future demands can also be met. Within water demand management, issues and subjects examined include: the collection of data and information on water use and pricing in both the municipal and the industrial sectors of the economy; the analysis of demand patterns and the factors that influence them; the forecasting of trends in water demands at different scales; the application of full-cost pricing principles to issues of municipal infrastructure; exploration of water demand management and conservation alternatives for water development; and the examination of the willingness of individuals to pay to assure adequate water services (Niewiadomy and Molina, 1989; Epsey, Epsey and Shaw, 1997; Saleth and Dinar, 1997).

1.7 Limitations of the Research

The thesis focuses solely on the residential component of municipal water demand. It does not examine commercial, industrial, or any other component of these demands. Although the latter are no doubt important, they have been excluded from this study, because factors influencing these other categories of demands can be different. Also, water quality issues have not been addressed, although again these are recognised as being important; of all the environmental issues affecting municipalities only issues affecting residential water demand have been addressed.

As mentioned above, studies of municipal water demand have traditionally fallen into two categories intra-municipal and inter-municipal, and the variables involved in the two types of studies may differ. Relatively few Canadian studies have been completed in understanding the nature of residential water demand and to the factors that determine it. Kellow (1970) reported on the impacts of metering by comparing two large Prairie municipalities, Calgary (unmetered) and Edmonton (metered); Grima (1972) observed the different factors outlining demand within the regional municipality of Toronto; Sewell and Roueche (1974) completed a similar analysis to that of Grima's for the municipality of Victoria; and finally, Renzetti (1999) analysed the factors underlying demand for water within Vancouver. Fewer inter-municipality studies have been carried out. Howe and Linaweaver (1967) examined the determinants of residential water demand across regions in the United States. To this date, a similar study has not been undertaken for Canada. The research is, therefore, intended as a contribution to filling that void. This study does not include considerations of an intra-municipal nature (e.g., household size, number of water using facilities, etc.).

CHAPTER II

A Review of Water Demand Studies

This chapter reviews the published literature pertaining to municipal water demand in general, and residential water demand in particular. This review is organized into two major sections. The first section places Canadian residential water demands into various contexts, which will be relevant in later parts of the study. The second section examines the literature relevant to the variables to be used in the linear regression models outlined in Chapter 3, and used in the analysis, the results of which are presented in Chapter 4.

2.1 Canadian Water Demand Patterns

There are many different contexts within which residential water demand can be viewed. Three have been used here, selected because they are most pertinent to the analysis that follows in later chapters. The first context is a spatial one, namely an overview of total and residential water demand in various developed nations. This view will show that Canada has amongst the lowest prices and highest per capita uses in the world. The second context views municipal water demand in relation to other major withdrawal water uses in Canada. This will show that municipal water demands are relatively small in the context of other withdrawal water demands. Despite this basic fact, it is also true that the use of publicly supplied water is normally an individual's primary contact with water resources, and, accordingly, that this is an important field of study. The third context views residential demand relative to total municipal demand. This view will show that the residential demand sector is the most important in accounting for total municipal demand, amplifying the importance of conducting studies in this area.

Conceptually, this type of organization can be looked at as an application of the "cones of resolution" concept developed by the cyberneticist Stafford Beer (1968), and as illustrated in Figure 2. Beer's idea was that research problems could be approached from several spatial scales, growing in complexity and differing in detail as one moves down through the "cone". The literature review presented in this chapter can be conceptualized broadly in this manner, even though this is an adaptation, not an exact mirroring of Beer's idea.

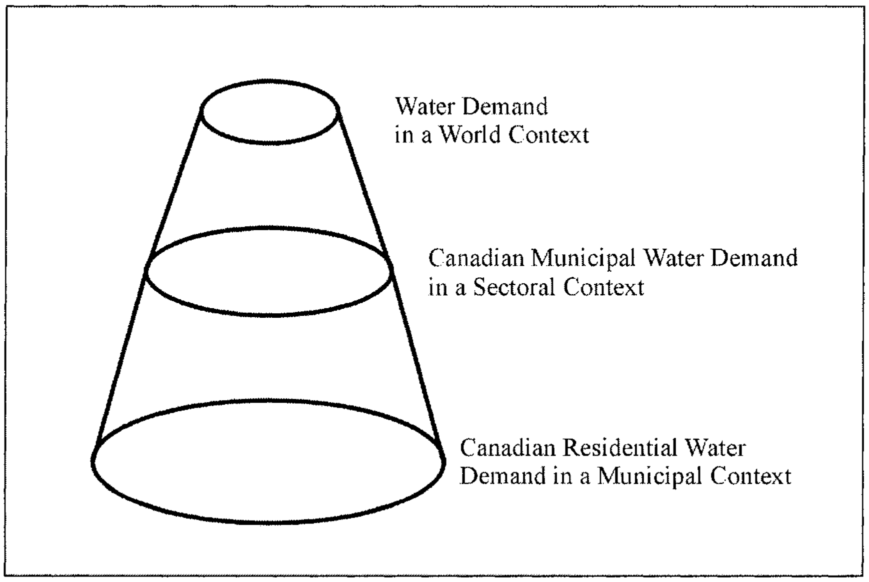

Figure 2: A Hypothetical Cone of Resolution for Canadian Residential Water Demand. (Source: Beer, 1968)

2.1.1 Canada in the Context of the OECD Nations

Canada's per capita water demand is amongst the highest in the world (OECD, 1987; OECD, 1999). Canada is second to the United States in terms of total national withdrawal water demand per capita, all sectors combined (Figure 3). For the OECD member countries included in the 1999 survey, average water demand was divided into the following proportions: 55% for industrial purposes (of which 44% was for power production and 21% for manufacturing use), 30% for agriculture, the remainder 15% divided into different municipal uses (OECD, 1999).

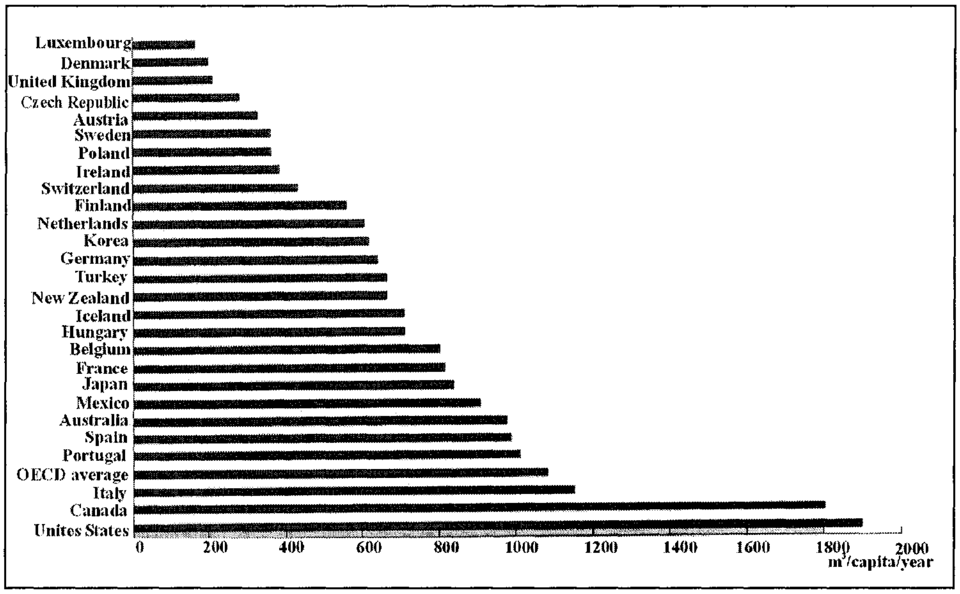

Figure 3: Average Per Capita Water Demand in OECD Countries, Mid-1990's. (Source: OECD, 1999)

Within residential water demand, Canada had the highest per capita usage levels, at 10 cubic meters per capita per monthe (m^3pcm). The OECD analysis assigned this level of demand as being within the "high-use" group (at more than 7.5m^3pcm), along with the United States, Australia and Japan (Figure 4). A core group of OECD countries followed, with average per capita demands between 3.75 m^3pcm and 7.55m^3pcm, nations with more arid conditions (e.g., Spain, Greece, and Turkey) had higher per capita residential water demands. Climatic conditions seemed to have a significant impact on per capita residential water demand.

A "low-use" group (i.e., those having usage rates of less than 3.75m^3pcm) included countries undergoing significant economic restructuring (i.e. Czech Republic, Portugal, Hungary) as well as those deemed to be established economies with water policies that encourage water conservation.

In terms of residential water pricing practices, Canada was included within the countries with the lowest charges per cubic meter. It was accompanied by countries such as Korea, the Czech Republic, Hungary and Italy. These all shared an average rate per cubic meter lower than $1US[1]. Countries with the highest unit prices were France, the Netherlands and Denmark (over $3US). These statistics placed Canada in a position wherein average water prices were consistently lower than in other nations and residential per capita demand values were especially high.

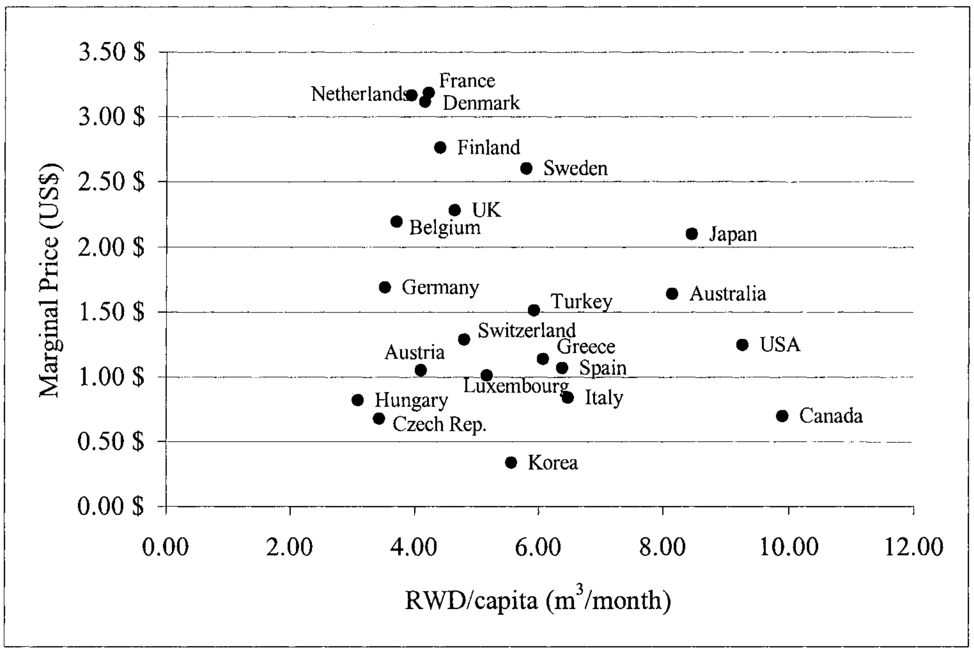

Figure 4: Country's Average per Capita Use with Regards to Price. (Source: OECD, 1999)

Figure 4 shows several interesting features. First, there appears to be a weak inverse relationship between marginal water prices and residential water demand per capita. Countries, which appear to show this relationship, include the Netherlands, France, Denmark, Finland, Sweden, Japan, Australia, U.S.A., and Canada. However this price/quantity relationship is modified by several factors such as aridity (Turkey, Greece,

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[1] All pricing values were transferred to US dollars constant to a 1998 value. Values were taken from OECD (1999).

and Spain), economic development (Hungary, Czech Republic, and Korea), and possibly environmental policies, which encourage water conservation (Germany, Austria, Switzerland, Luxembourg, and the U.K.). Therefore, although there appears to be a price/quantity relationship, as suggested in the water demand literature cited below, there are several other factors that may be important in influencing per capita residential water demand.

2.1.2 Sectoral Water Demand Patterns Within Canada

Within the Canadian context, water demands varied substantially between both regions and sectors (Table 1). For example, in 1991[2], the total water demand, all sectors combined, was of 45,100 million cubic meters. The thermal power industry accounted for the largest share of the total, representing approximately 63% of total demand. This sector, which includes both conventional and nuclear power generating plants, used almost all of its water for cooling purposes. A large percentage of this sector's water demand took place in Ontario.

Manufacturing industries accounted for the second largest proportion of water demand within Canada. Several of the industrial sub-groups comprise this sector, which represents about 16% of the total national withdrawal water demand. The major sub-groups included paper and allied products, chemicals, and primary metals.

Municipal water demand was the third of the major water use sectors, accounting for about 11% of the total national demand. This value does not include households connected to wells. Water demands within the municipal sector were divided between

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[2] For descriptive purposes, the year 1991 was used because data for that year were most accessible for readers. More current data are available, but not in a comprehensive compiled form. This is not an important issue, because Canadian water demand patterns are quite stable.

households, commerce, industry supplied from public sources, and institutions. This demand generally reflects population distribution.

Table 1: Canadian Sectoral Water Intake by Region, 1991.

Region	Sector[1]					Regional Total
	Thermal Power	Manufacturing	Municipal	Agriculture	Mining	
Atlantic	2,126 66.96%	601 18.93%	356 11.21%	15 0.47%	77 2.43%	3,175
Québec	1,005 22.34%	1,616 35.93%	1,703 37.86%	100 2.22%	74 1.65%	4,498
Ontario	23,095 81.08%	3,457 12.14%	1,660 5.83%	186 0.65%	87 0.31%	28,485
Prairies	2,025 32.55%	447 7.19%	685 11.01%	3,014 48.45%	50 0.80%	6,221
British Columbia[2]	106 3.90%	1,161 42.75%	698 25.70%	676 24.89%	75 2.76%	2,716
National Total	28,359	7,283	5,103	3,992	364	45,100
Percent of Total	62.88%	16.15%	11.31%	8.85%	0.81%	100.00%

Source: Environment Canada, 1993.
[1] Top values are in million cubic meters per year, while lower values of percentages are of regional total.
[2] This region includes the Northern Territories.

Agriculture water demand accounted for 9% of total water demand. This type of demand is dominated by the Prairie region, which contains most of Canada's irrigated croplands. Agriculture water demand is highly consumptive, with only a small part of the original intake being returned to ambient watercourses. Finally, mining water demand represented almost 1% of the total water demand, but varies slightly among the different regions.

2.1.3 Residential Water Demand Within Municipalities

Municipal water demand is comprised of three main types of use: residential, commercial, and industrial water demand[3]. Minor amounts are also used for institutional and public purposes, which are not included in this study. The largest proportion of municipal water demand is for residential purposes. Its share of total municipal water demand averaged 59% of the total municipal water demand between 1989 and 1999 for the two regions under study (Table 2). Commercial and industrial water demand shared the remainder parts of the total municipal water demand with values at 23% and 18% respectively.

Percentages for residential water demand were generally consistent throughout the years and the two geographical regions. However, variations are apparent between the Prairies and Ontario when comparing commercial and industrial demands as proportions to total municipal water demand. The Prairies generally had higher commercial water demand proportions (25% on average over the period of study), while industrial water demand averaged lower (16%). Ontario had higher industrial water demand proportions (21% on average) than the Prairies, with commercial water demand proportions also at 21%. These differences, however, reflect well-known economic contexts of the two regions – namely that the Ontario region is substantially more industrialized than the Prairies.

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[3] The majority of Canadian industrial establishments draw their water from municipal utilities. Only the largest industrial operations have their own water supply systems and even these establishments draw from municipal utilities to obtain water for in plant domestic and sanitary purposes.

Table 2: Types of Municipal Water Demands for Ontario and the Prairie Provinces (1989-1999).

Region	Year	Volume of Usage ('000 m^3/month)				Percentage of Usage		
		Residential	Commercial	Industrial	Total	Residential	Commercial	Industrial
Ontario	1989	82,422	28,595	30,630	141,647	58%	20%	22%
	1991	71,600	22,038	20,905	114,543	63%	19%	18%
	1994	66,614	29,906	39,641	136,161	49%	22%	29%
	1996	87,728	35,206	26,667	149,601	59%	24%	18%
	1999	96,544	35,109	28,266	159,919	60%	22%	18%
Prairies	1989	32,069	11,161	7,120	50,349	64%	22%	14%
	1991	27,491	14,048	8,639	50,178	55%	28%	17%
	1994	29,912	12,252	9,848	52,012	58%	24%	19%
	1996	27,656	11,568	7,606	46,830	59%	25%	16%
	1999	30,708	12,668	6,392	49,767	62%	25%	13%
Source: based on Environment Canada MUD datasets for respective years.								

2.2 Factors Underlying Residential Water Demand

In terms of the research that has been carried out on residential water demands, several behavioural variables (i.e., variables that influence households in their water use choices) have been used to model these demands. This section presents an overview of these factors in order to set the stage for the model that will be developed in Chapter 3. Key terminology to be used throughout this research will also be defined within this section.

There is a considerable amount of scientific literature on residential water demand. The literature mainly focuses on the specific nature of the relationships between the quantity of water demanded and a set of explanatory variables suggested by economic theory. This literature centres on the definition of the price variable (and subsequently pricing structure), as well as a series of other explanatory variables, climatic influences being at the forefront of this research domain.

2.2.1 Population

One of the most significant factors in determining residential water demand is the number of persons connected to the water-servicing infrastructure. In fact, the most common form of water demand forecasting employed in the past has merely multiplied per capita water demand "coefficients" by projected population levels to produce water demand "forecasts". This method has been criticized by many researchers in the past (e.g., Whittington, 1977; Tate, 1985) as being overly simplistic, in that all of the variation in water demands are "loaded" onto this one variable, thereby offering few choices for developing policies to alter demand levels.

To some extent, this criticism may or may not be accurate depending upon the geographical scale of the study being undertaken, or the particular task at hand. To anticipate the results of the current research slightly, it was found that municipal population levels, in fact, explain most of the variance in total residential water demand. This suggests that population levels are important in explaining inter-municipal water demands (i.e., water demands between a set of municipalities) but says nothing about the explanation of intra-municipal demands (i.e., water demands within individual municipalities). This will be discussed in more detail in Chapter 5.

2.2.2 Price Structure and Metering

There exist different types of water pricing structures within municipalities. A first distinction must be made between rates based on flat charges and those that vary with consumption. Flat charges are entirely independent of the quantity of water used; a fixed price is charged for unlimited access to public water supplies (and, often, waste treatment services as well).

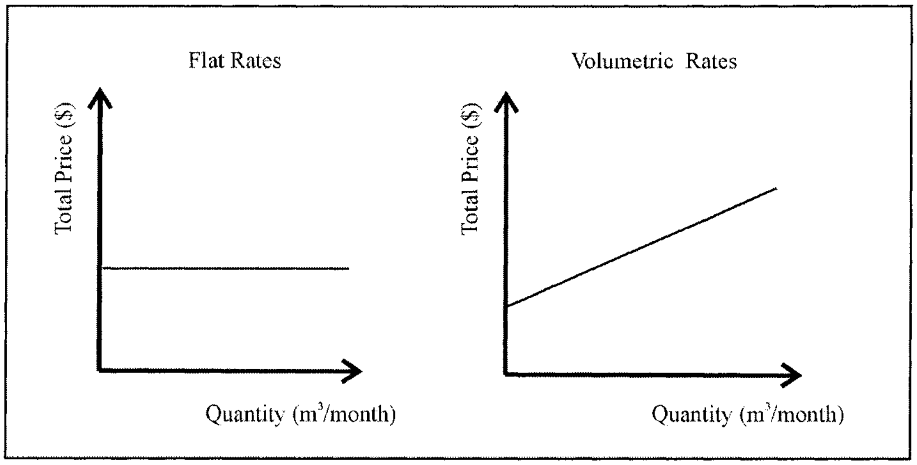

Figure 5: Total Price Variations Between Flat Rate and Volumetric[4] Pricing Structures.

The second method of charging can be termed volumetric, because the price of water depends on the volume of water demanded. The distinction between the two basic methods of pricing are illustrated in Figure 5, which plots the total amount of money paid by a hypothetical residential user per billing period across a hypothetical range of demand. The flat rate user pays a fixed price per billing period, as shown by the horizontal total price line paralleling the X-axis. The volumetric user's total price line, on the other hand, slopes upward to the right, indicating that the total price paid increases with quantity demanded. Volumetric charging requires service connections to be metered.

Within the volumetric class of water pricing, there are three basic variants: constant unit charges (CUCs), decreasing block rates (DBRs), and increasing block rates (IBRs). These methods are illustrated in Figure 6, which varies slightly in form from Figure 5. In Figure 6, the marginal price for water per unit of demand (e.g., per m^3) is used on the Y-axis instead of total price per billing period, because marginal price is somewhat more convenient to illustrate the point. Marginal price is used here in the economic sense to denote the price of the marginal, or "extra" unit of demand. The CUC

[4] The figure represents a uniform rate charge structure within the broader category of volumetric charges.

method levies a constant price per unit of demand[5], and the marginal price line is horizontal, parallel to the X-axis. The other two volumetric pricing systems rely on dividing the consumer's demand into "blocks", or ranges of demand, for example 0 m^3 to 10 m^3, 11 m^3 to 20 m^3, etc. Within each block, the marginal price is constant, but changes between blocks. For IBRs, the marginal price increases across the blocks; for DBRs, it decreases. (For flat rates, the marginal price is zero; the marginal price line would be the X-axis.)

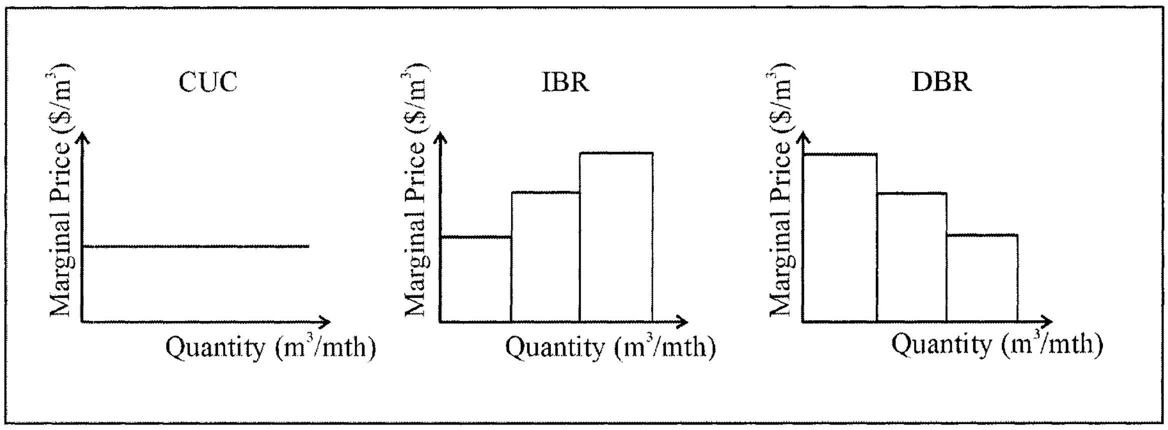

Figure 6: Variations of Marginal Prices for Sub-Sections of Volumetric Pricing.

In terms of water demand, these four rate "structures" (i.e., flat, CUCs, DBRs, and IBRs) have interesting theoretical implications, based on the fact that demand in responsive to marginal price. For flat rates, as indicated, marginal prices are zero, and offer no incentive for water saving, or conservation. This pricing system encourages excessive water demands, as will be illustrated in Chapter 3. The three volumetric rater structures offer varying incentives for water conservation, basically because marginal prices are positive. With DBRs, these incentives, though positive, decline through the range of demand (i.e., across the blocks); DBRs are thus considered to be "weak"

[5] CUCs are similar in operation to the purchase of automobile fuel or most foodstuffs. In the general economy, this, in fact, is the most common method of pricing.

incentives for water conservation. The CUC methods offers somewhat stronger incentives for conservation, because the marginal price to the consumer is constant. IBRs offer the strongest conservation incentives, because marginal water price increases as usage increases.

In Canada, flat rate charges make up 58% of the residential water rate charges (percentages in this paragraph are taken from Tate and Lacelle, 1995). These are, however, found mostly in smaller municipalities. In terms of population, 50% of the Canadian urban population is serviced by flat rates. Surprisingly, all or parts of some of Canada's largest cities are unmetered, such as Montréal, Toronto, and Vancouver. The remaining residential rate schedules are volumetric, distributed as follows: CUC (22%), DBR (15%), and IBR (3%).

As previously mentioned, the installation of individual meters is needed in implementing volumetric-based rates within municipalities. Studies have shown that municipalities, which are metered, have lower per capita water residential water uses and therefore lower total water use, other things remaining equal. Communities without meters are forced to use flat rate pricing, thereby encouraging excessive water demand. In 1994, households that were provided with meters demanded 39% less residential water than those that were unmetered (Environment Canada, 1998).

In Alberta, Kellow (1970) found that water demand in the unmetered, flat rate areas of Calgary was substantially higher than water demand in the (predominantly) metered (and volumetrically priced) areas of the city of Edmonton, an urban area of comparable size and geographic location where volumetric pricing was used. The unmetered households in Calgary demanded about 46% more water, while metered users in both cities demanded about the same amount.

Grima (1972) reported similar variations in residential water demand levels between unmetered and metered households, in Etobicoke (Ontario). Residential water demand in the unmetered areas was 45% higher than in the metered areas of comparable property size and value.

Loudon (1986) reported on the effect of metering in four Canadian municipalities (Table 3). The percentages of change in municipal water demand varied between 15% and 32% from pre-metering practices to post-metering ones.

Table 3: Effects of Metering on Municipal Water Demand.

Municipality	Pre-Metering Demand [1]	Post-Metering Demand[1]	% in Change
Kingston, ON	31	23	25%
Brockville, ON	27	23	15%
Ottawa, ON	18	13	27%
Calgary, AB[2]	36	24	32%

Source: Loudon, 1986.
[1] All values are in m^3/person/month. These figures represent total municipal water demand, not only residential water demand.
[2] Estimated effects only.

A large number of additional studies demonstrate the effect of metering on residential water use. For example, rigorous comparison of metered versus unmetered water demand was developed by the Johns Hopkins Residential Water Use Project in the mid 1960's. A sample of 39 areas in the United States, each including a relatively homogenous residential district, was master metered during the period of 1961 to 1965. Demands were recorded every 15 minutes. The study included 10 metered areas with public sewers; 5 with septic tanks; and 5 apartment building areas without individual residential metering. The results of this study are shown in Table 4.

Table 4: Water Use in Metered and Flat Rate Areas in the Western United States.

Annual average	Cubic Meters per day per household	
	Metered	Flat rate
Leakage and waste	0.095	0.1368
Indoor use	0.9386	0.8968
Sprinkling	0.7068	1.596
Total household water use	1.7404	2.6296
Peak hour	9.4278	19.646
Source: Linaweaver, Beebe, and Kriven (1966); as cited in Billings and Jones (1996).		

Apart from showing a large per capita water demand in all cases, but particularly in the case of peak hour demands, Table 4 demonstrates that total metered household demand was about 50% of that of unmetered demand. Table 4 also shows that metering has a much more significant impact on outdoor water use than it does in indoor use.

Table 5 summarises the results of a number of additional studies of water metering carried out in the past. These all show substantial drops of residential water demand as a result of meter installation.

Finally, a recent study by Harris and Tate (2002) makes the following observations:

> "This table (i.e., Table 6 in the present study) summarizes the metering-related results of a recent water use and pricing study in Ontario for the period of 1989-1999. The impact of water metering on water use can be deduced from this table. Most of the communities in the two smallest population size categories are dominated by the use of flat rate water pricing practices, and it can be inferred that these municipalities have no water meters. The table shows that per capita water usage declines significantly from the smaller municipalities to the largest communities in Ontario. Generally, the latter are mostly or fully metered with respect to their water supplies. These communities have significantly smaller per capita residential water usages. This demonstrates again that the impact of water metering on municipal water demand is substantial."

Table 5: The Effects of Metering on Municipal Water Use – Selected Studies.

Area	Impact and Special Details	Source
Western U.S.	Unmetered areas have over 50% higher water use than metered ones on average; over 100% for maximum day and maximum hour.	Linaweaver, Geyer and Wolff (1967)
Etobicoke - Ontario	Unmetered areas have 45% higher water use than metered areas of comparable assessment.	Grima (1972)
St-Catharines, Ontario	An 11% drop immediately following metering but rebounds because prices kept low. Two years later, water usage higher than before metering.	Pitblado (1967)
Alberta	10-25% drop in water use following meter installation	Associated Engineering Services Ltd. (1980)
Peterborough, Ontario	10% reduction in water use predicted following meter installation.	Peterborough Water Department (1984)
Central Valley, California	Household water use reduced up to 55% following meter installation; usage averaged 30% less in metered than in unmetered cities.	Minton, Murdock and Williams (1979)
Calgary, Alberta	Unmetered water use 46% greater than that in metered residences.	Mitchell (1984)
Calgary, Alberta	Unmetered water use 65% greater than that in metered residences.	Kellow (1970)
Dallas, Texas	Experienced a drop in water demand of 43% following meter installation.	Shipman (1978)
Gothenberg, Sweden	Per capita use in unmetered apartments 50% higher than in a single family, metered residences.	Shipman (1978)
York County, Pennsylvania	Substantial increases in industrial waste treatment charges led to reductions in water use in the range.	Sharpe (1980)
	Source: Harris and Tate, 2002.	

Unmetered households also weaken the economic and financial viability of the municipal water servicing industry by causing excessive demands. Since water-servicing infrastructure is the most expensive of all public and quasi-public utilities, excessive demands impose high, but largely unrecognized, social costs. Also, interestingly, the water utility industry is the only one of comparable size that consistently fails to measure the volume of its primary output (i.e., potable water). These problems are principally reflected in Canada by a generally deteriorating water infrastructure (Environment Canada, 1987). These issues will be discussed in greater detail in Chapter 5.

Table 6: Monthly Residential Water Demand in Ontario per Capita, by Population Size Group.

Size Group ('000 persons)	1989	1991	1994	1996	1999
1 - 5	14.05	13.30	13.20	13.16	13.34
5 - 10	13.93	12.16	12.60	13.03	14.10
10 - 50	12.40	11.93	11.10	10.35	10.65
50 – 100	10.88	10.03	9.60	9.21	9.76
>100	9.23	9.56	9.60	9.49	10.45
Total	10.42	10.43	10.20	9.81	10.54

Source: Harris and Tate, 2002.
[1] Values of water demand are in m^3 per month.

2.2.3 Price

As already indicated, residential water demand is inversely related to the price of water. Economists working in the water demand field generally employ the concept of price elasticity of demand to characterize this relationship[6]. Price elasticity of demand measures the change in water demand resulting from a change in water price. Mathematically, price elasticity is defined as the percentage change in demand divided by the percentage change in price at a given point on the demand curve – in other words, the slope, or first derivative, of the demand curve at a given point. The slope of demand curves vary as one moves along the curve, and thus, elasticities of demand vary, depending on the measurement point. Clearly, measuring elasticity at point a of the hypothetical demand curve in the left hand panel of Figure 7 will yield a value different from a measurement taken at point b. The procedure used to circumvent this problem of varying slope along a demand curve is to logarithmically transform all measurements. This produces a straight line with a constant slope[7], as in the right hand panel. This type of "curve" is assumed throughout the remainder of this discussion.

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[6] Throughout this discussion, price elasticity of demand is assumed to pertain to water demand, even though the concept is a general one.
[7] This slope is measures as the exponent of price, resulting from regression analysis, as dealt with in Chapter 4.

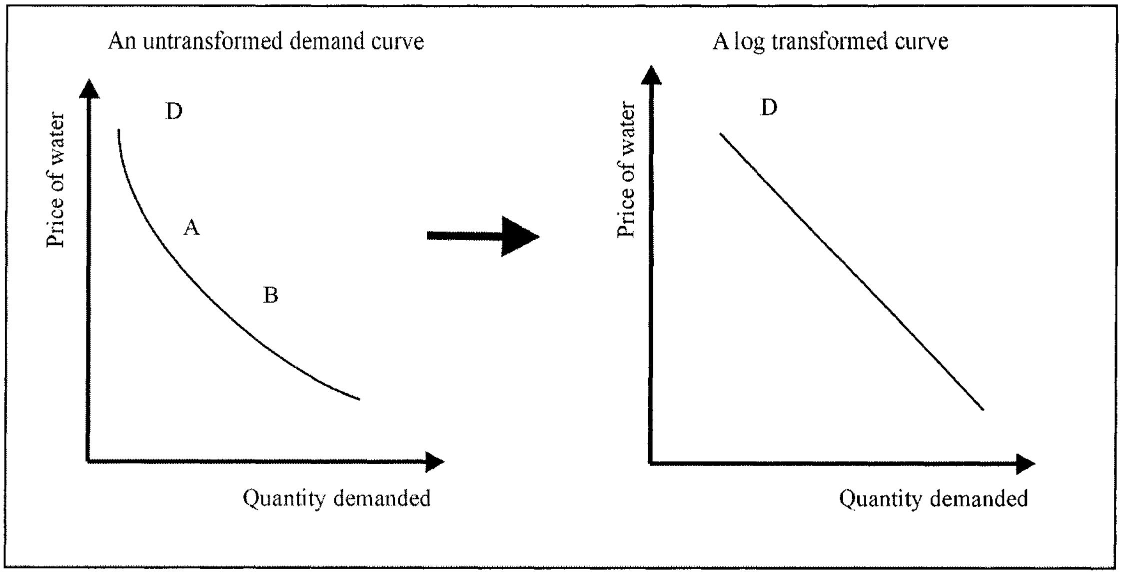

Figure 7: Effects of Logarithmic Transformations of Demand Curves.

Clearly, the slope of a transformed demand "curve" is negative in number and can vary. The negativity issue is normally addressed by referring to elasticity values in absolute terms. Curves with (absolute) slope values between zero and one are termed "inelastic", while those with slope values greater than one are termed "elastic". In practical terms, price elasticity values indicate the availability of substitutes for a given water use. Relatively inelastic demands, such as demands for indoor water, reflect a relative lack of substitutes for these water uses; indoor elasticity values fall generally into the 0.2 to 0.4 range (Figure 8). Outdoor water uses have more substitutes than indoor, with correspondingly higher values, generally on the 0.5 to 0.7 range (Harris and Tate, 2002).

The elasticity issue is important in water demand studies for at least two reasons. First, the elasticity value allows an estimate of the reaction of demand to price changes. Household water demand falls into the inelastic range, implying that a give percentage change in price will produce a less than proportional change in demand. This is useful in long-term rate design and infrastructure planning. Second, and corollary, knowledge of elasticity values allows estimation of the revenue implications of water price changes. In general, price increases under inelastic demand conditions will result in increases in overall revenue for the water utility.

Howe and Linaweaver (1967) initiated the discussion on the relevance of average and marginal prices for demand models specification by arguing that consumers react to marginal rather than average prices. Recent studies have included average prices (Billings 1990; Hogarty *et al.* 1975), marginal prices (Danielson 1979; Lymann 1992), or both (Opaluch 1982; Martin *et al.* 1992). Shin (1985) began to make use of the perceived price, which can be defined as a combination of both marginal and average price. Perceived prices have consequently been used in other studies (Nieswiadomy 1992; Nieswiadomy and Cobb, 1993).

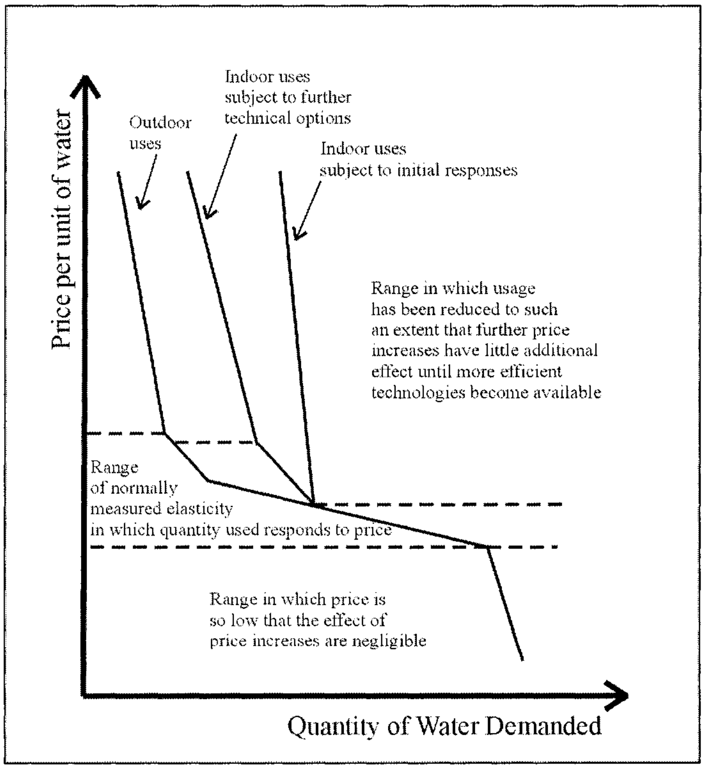

Figure 8: Conceptual Demand Curves for Residential Water.

(Source: Brooks *et al.*, 1990)

2.2.4 Income

In addition to the influence of price, the water demand literature demonstrates that the level of residential water demand can also be a function of the level of household income. This relationship is a direct one, in the sense that the higher the income level, the higher the level of water demand (other things being equal). The logic here is a straightforward one: higher income households have access to more household water using equipment (washers, dishwashers, more bathrooms, etc.) than do lower income ones (see, for example Billings and Agthe, 1980a, 1980b).

As in the case of water prices, the concept of an elasticity value is used as the primary measure of the effect of income. Income elasticity of demand is measured as the percentage change in the quantity demanded divided by the percentage change in price; for example, in this case, in the case, the percentage change in water demand produced by a one percent change in income. It measures the responsiveness of demand to changes in income.

Headley (1963) tested residential water demand as a function of income within fourteen municipalities in the San Francisco-Oakland Metropolitan area that shared similar characteristics (i.e., precipitations and temperatures as well as price). The research showed that income was a highly significant determinant of residential water demand. In fact, income elasticities were very high, varying from 1.4 to 2.3.

In contrast to price elasticity of water demand, income elasticity is positive in value. Past studies have shown estimated income elasticities to fall generally into the inelastic. Values generally vary from 0.3 to 0.8 (Wong, 1972; Gibbs, 1978). Other studies estimating income elasticity values for water demand can be found in Annex 1.

While studies focussing on the effects of income levels on water demand are less common than those for price, some interesting facts have emerged. Outdoor water demand accounts for nearly half of the total residential water demand in drier regions. Outdoor water demands are highest within the high-income group (Brooks *et al.*, 1990). For example, swimming pools are more common, and, particularly in the Southern and Southwestern U.S., evaporative cooling is often used as a form of air conditioning, or to supplement electrically operated air conditioning. High-income groups are also the first to adjust their practices and lower their residential water demand. These two findings suggest that higher income households have higher income elasticities of water demand than lower income ones. Finally, income elasticity values are of higher statistical significance in the context of average outdoor demand better than of maximum day demand (Howe and Linaweaver, 1967).

2.2.5 Density

Few studies in the past have addressed the issue of the impact of density on residential water demand. As used here, density refers to the concentration of population per square kilometer in each of the municipalities included in the study. From a theoretical viewpoint, it seems logical to argue that as population density increases, lower water use for outdoor purposes (i.e. lawn watering, gardening, etc.) can be expected. Grima (1972), for example, took this viewpoint, arguing that the density of housing units will tend to lower residential water demand per capita. Nauges and Thomas (2000) also took this viewpoint, holding that, because lawn watering comprises a substantial proportion of residential water demand, a decrease in residential outdoor use per capita will occur as density increases.

2.2.6 Rainfall

As previously outlined, one of the major uses for residential water is in outdoor water use. It can be expected than with any given region indoor water usage rates will be roughly similar. (Foster and Beattie, 1979; Howe, 1982) However, the demand levels for outdoor water use will be dependent in part on the amount of precipitation occurring particularly during the summer months. Therefore, as average precipitation increases water demand will decrease (Howe and Linaweaver, 1967; Griffin and Chang, 1990).

Akuoko-Asibey *et al.* (1993) tested different climatic variables with residential water levels in Calgary, AB. It was found that precipitation levels were highly correlated with residential water demand. In fact, using climatic variables the research found rainfall data to be strongly statistically significant.

CHAPTER III

Analysing Residential Water Demand: A Methodological Excursion

This research is aimed at explaining variations in two dependent variables, total residential water demand and residential water demand per capita, using simple and multiple regression analysis employing a number of independent variables. This chapter discusses the details of the procedures used to carry out this task. Initially, some basic information is presented on the two regions analysed in this study. This is followed by an outline of the functional form of the hypothetical models used, focusing on a discussion of the dependent and independent variables. Then, the chapter addresses the nature of the statistical techniques used to carry out the analysis. Particular attention will be paid here to the issue of correlation analysis, and the results obtained from carrying out this analysis[8]. The chapter concludes by transforming the functional form models into the mathematically more precise models used to derive the research results.

Regression analysis was selected as the main technique for conducting the research, and is dealt with in section 3.6.2. To anticipate this discussion, the basic problem addressed here is one of drawing relationships between a dependent variable and a number of independent variables. Throughout the water demand field, and many other fields of study (both in geography and in other disciplines), these types of problems have been addressed using regression techniques. Other techniques are possible, such as factor analysis, but these were discarded because the regression analysis technique appeared more suitable.

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[8] It is acknowledged that much of the discussion dealing with correlation focuses on results obtained, and that these results might, more appropriately, be dealt with in chapter 4. The discussion appears in chapter 3 instead because the correlation analysis results are important in specifying the mathematical nature of the two models used in the analysis, an issue described in section 3.8.

At its most basic, a model is an abstraction of reality. In other words, the subject under study is stripped down to its most fundamental components, which are then presumed to "explain" the major characteristics of the phenomenon under study. For example, a regression equation uses a set of independent variables (i.e., the fundamental components referred to above) to "explain", or account for variations in a dependent variable (i.e., the phenomenon under study). A regression model can therefore be viewed as a model of description. In other words, a model is a formalized presentation of ideas or of a certain amount of knowledge about a specific phenomenon (Schilderinck, 1977). The creation of this model implies that insight has been obtained into the most important elements that explain the variations of the dependent variable. The purpose of these models is to simplify complex realities into a series of fundamental equations, using variables that approach the reality of the dependent variables. Other types of modeling activities relate to descriptions of processes that operate to produce observed results – for example, erosional models in geomorphology. These types of models are mentioned here merely to stress that the models used in this thesis are of the descriptive type only.

3.1 Region of Study

As outlined in Chapter 1, the study focuses on two Canadian regions: Ontario and the Prairies (Manitoba, Saskatchewan, and Alberta) (Figure 1). This selection of geographic units was used for two reasons: spatial comparisons and sample sizing.

With respect to the first reason, the Prairie region has water availability characteristics quite different from those in Ontario, in that, the former is considered a semi-arid region while the latter is considered a humid region.

Water availability in the Prairie region is dependent on spring runoff from the Rocky mountain snow pack. It is characterised by lower annual precipitation levels and is more limited with their water supply. Ontario, on the other hand, is considered water abundant (Tate, 2002). Although there are certainly exceptions to this consideration (e.g., smaller communities entirely dependent on groundwater supplies), annual river flow rates display less seasonality. Therefore, surface water sources are more reliable within this province (Table 7). The second reason for considering these two regions has already been outlined - namely that they have approximately the same number of municipalities for each of the study years.

Table 7: River Flow Rates for Provinces within the Region of Study.

Region of Study	River Basin Region	Flow Rates	
		Low (reliable)	High
Prairies	Peace-Athabasca	1,862	3,946
	Missouri	3	41
	North Saskatchewan	160	373
	South Saskatchewan	147	418
	Assiniboine-Red	16	188
	Winnipeg	382	1,137
	Lower Saskatchewan-Nelson	1,108	2,714
	Churchill	323	1,070
Ontario	Keewatin	2,945	4,806
	Northern Ontario	3,733	8,258
	Great Lakes	2,403	3,733
	Ottawa	1,390	2,590
	St.-Lawrence	1,504	2,777

Source: Pearse *et.al.*, 1985.
[1] Measured in cubic meters per second.

3.2 Models Employed – Functional Form

The functional forms of the two models used in the research are given by the following equations:

$$TRWD = f(Pop, PS, P, I, SP) \qquad \text{(Equation 1)}$$

$$RWD/cap = f(PS, P, I, D, SP) \qquad \text{(Equation 2)}$$

Where:

TRWD =	Total residential water demand
RWD/cap =	Residential water demand per capita
Pop =	Population served by water services
PS =	Pricing structure
P =	Price of residential water
I =	Income
D =	Density
SP =	Rainfall, summer precipitation

A more precise specification of the models used will be discussed in section 3.6.4, following a discussion of the nature of the variables, data sources and types, and a detailed correlation analysis of the inter-relationships between variables.

3.3 Dependent Variables

3.3.1 Total Residential Water Demand (TRWD)

Total residential water demand is defined as the amount of residential water demanded for residential purposes in each municipality in each time period. Selected independent variables were regressed against this dependent variable to explain variations in residential water demand as indicated in Chapter 1. Data on total residential water demand were derived from Environment Canada databases, which are discussed in detail in section 3.3.3 below. Total residential water demand was defined as the average monthly[9] amount of water demanded, measured in cubic meters, in the respective municipalities for each of the five years included in the study period.

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[9] Average monthly data are used as a measure of residential water demand because the pricing data contained in the MUP database are calculated in monthly terms. In the MUD database, water use

3.3.2 Residential Water Demand per Capita (RWD/cap)

Residential water demand per capita is defined as the amount of water demanded, for residential use, in each municipality, divided by the municipal population. This dependent variable was selected to eliminate the effect of population size. This variable also allows for the analysis of different independent variables from the total residential water demand model, such as density. Residential water demand per capita was measured as total residential water demand divided by total municipal population served by public water supplies for each of the years included in the study.

3.4 Independent Variables

3.4.1 Population

For the purposes of this study, population is defined as the number of persons served by public water supplies within each municipality. As the number of persons connected to the water servicing systems increases, total residential water demand will increase. Population served by water services for each municipality were derived from the MUD database.

3.4.2 Price Structure

Two types of price structure were used: flat rate and volumetric rates. The different types of volumetric rate structures were not differentiated. Communities with a flat rate structure will use more water on average than communities with volumetric structures. The types of rates are available through the Environment Canada surveys. Within this study the various types of volumetric rates were abstracted into to one

information is recorded in daily terms. To calculate average monthly water demand the daily figures were multiplied by 30.

variable. A dummy variable was used to represent each type of rate where zero equals a flat rate and one represents a volumetric rate.

3.4.3 Price

A significant debate on the choice of pricing variable is found within the literature; therefore two measures of price were used in the study: total price and marginal price. Total price is defined here as the total amount of money paid per month, by residential customers, for $35m^3$ of water services.[10] This volume of water is approximately the monthly demand of an average Canadian family. The average monthly use would be approximately $30m^3$ per month. Tate and Lacelle (1995) estimated prices for $25m^3$ per month and 35 m^3 per month. The latter value has been chosen to allow an estimate for extra water demand during summer months. Marginal price is defined as the additional amount of money paid for an extra cubic meter of water at the $35m^3$ per month level. Economic theory shows that consumers should react to marginal prices (Opaluch, 1982). An inverse relationship is expected between the price of water and water demand. Price data were derived from the Environment Canada MUP database for the respective years being covered in this study.

Price was measured in terms of constant 1992 dollars, and the consumer price index was used to deflate all years to 1992 terms (Table 8) (Statistics Canada, 1999, 1996, 1995, 1994, 1991, 1989).

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[10] This includes all relevant charges for waste treatment by the municipality.

Table 8: CPI Coefficients for Water Services.

CPI values for water (100=1992)

Year	Value
1989	93.8
1991	99.5
1994	101.2
1996	105.3
1999	104.8
Source: Statistics Canada for respective years.	

3.4.4 Income

Income was defined as the amount of money flowing to individuals in the economy from various factors of production, such as land, labour, or capital (Crane, 1993). As indicated in Chapter 2, residential water demand is directly related to average income levels – that is as income grows, residential water demand grows as well. Income was measured as the average household income in each of the municipalities included in the study. Average income statistics were drawn for 1991 and 1996 from the census. Data for 1989, 1994, and 1999 were not available. Income values are measured in terms of 1992 dollars.

3.4.5 Density

Density is defined as the population per square kilometre for each of the municipalities included in this study. Residential water demand was hypothesised to be inversely related to density. As implied in the definition, this variable is measured as the population per square kilometre in any given municipality. Population data were taken from population statistics within the MUD database. Area data were taken from census publications. Where area values changed during inter-censal years, appropriate adjustments were made. For example, where area values changed between census years, a search was conducted in the map library of the respective municipalities to determine when the area change occurred. This search formed the basis of adjusting the inter-censal area measurements.

3.4.6 Rainfall

This variable was measured as the summer rainfall in each municipality in the study. An inverse relationship between water demand and precipitation were expected, because as summer precipitation increases (decreases), less (more) water will be required from the public water system. This change will be reflected in the water supply section of the MUD database. Summer precipitation values were found from climatic data available from Environment Canada (Environment Canada, 2002a, 2002b, 2002c).

Totals for the months of June, July, August, and September were found for each climatic station within the provinces of the study. Using ArcView 3.2®, each municipality within the databases was associated with the closest climatic station for each of the given years.

3.5 Databases

3.5.1 MUD and MUP Databases

The municipal water use database (MUD) was established by Environment Canada in 1976. This database accounts for the use of municipally supplied water among different user groups, defines the sources of water supply for municipal systems, and describes the basic characteristics of wastewater treatment. From 1976 to 1986, this survey collected data for all municipalities in Canada with population over 5,000 persons, and a sampling of municipalities with populations between 1,000 and 5,000 persons.

Commencing in 1989, all municipalities in Canada containing populations over 1,000 persons and supplied with water from a central distribution system were surveyed. From 1989 to 1999, the period under study, the MUD survey contained the same basic parameters. Annex 2 describes the MUD database in detail. In summary, the MUD database was established to account for the physical nature of water use and municipal water infrastructure within Canadian communities.

Beginning in 1983, the MUD surveys were augmented with a request for water rate schedules for the respective municipalities. The sample sizing parameters followed the same procedures as those described for the MUD surveys. However, a new database was established, called the Municipal Pricing Database (MUP) (see Annex 3). The contents of the individual municipal water rate schedules were and still are extremely diverse across Canada. Accordingly, a set of standard analyses for the rate schedules was established. This standard included such things as: the type of rate schedule, the marginal price per cubic meter of water, the number of blocks in the rate schedule, the size of the blocks, and a calculation of the cost of selected volumes of water use within the municipalities. For residential consumers, the standard volumes selected were $10m^3$/month, $25m^3$/month, and $35m^3$/month. The first volume accounted for users with minimal monthly requirements, while the second two volumes approximated the volume of water used by typical Canadian families. For the purposes of this research, only the $35m^3$/month level was analysed.

For both the MUD and the MUP databases, data collection was conducted on the basis of census years (i.e. years ending in one and six) plus an additional year in between census years. For example, 1994 was chosen to be the inter-censal year between 1991 and 1996. Similarly, 1999 was the inter-censal year between 1996 and 2001.

The combination of the MUD and MUP datasets contains data on the water demands and prices of approximately 75% of the population within the regions of study. It is the most comprehensive water use database available for Canada. The provinces in the regions under study do not collect the data contained in the MUD and MUP databases. These databases also offer consistency in the measurement of data, providing the same information across the different provincial jurisdiction at study. The data was suitable for the topic at hand and was therefore accepted without any additional sampling undertaken. However, the MUD and MUP datasets do not provide any disaggregation of residential water into outdoor and indoor end uses.

3.5.2 Meteorological Survey Data

The Canadian Daily Climate Data, gathered by the Meteorological Service of Canada, is administered by Environment Canada. The Service monitors water quantities, precipitation and temperature levels. It provides information on the national climate and surface water (hydrometric and sediment) data archives. The National Archives and Data Management Branch, Atmospheric Monitoring and Water Survey Directorate of the Meteorological Service of Canada maintain these datasets and compile them into CD-ROMs.

The climatic data was used within the research for the rainfall variable. In total, data for 4861 stations was gathered (Table 9) and combined with the MUD and MUP datasets to account for summer precipitation values within the municipalities under study. Daily climatic data was compiled and only stations with complete records were retained for the purpose of the study.

Table 9: Number of Meteorological Stations within the Region of Study in Service from 1989 to 1999.

Province	Number of Meteorological Stations
Alberta	1454
Manitoba	673
Saskatchewan	807
Ontario	1927
Source: Environment Canada (1999a).	

3.5.3 Census Data

Census data on E-STAT are available for the following geographic levels: Canada, the provinces and territories, census divisions (counties, regional districts, regional municipalities, etc.) and census subdivisions (municipalities, Indian reserves, etc.) and census tracts (neighbourhoods) for the major Canadian cities. Census data is compiled every five years by Statistics Canada. The 1991 and 1996 censuses provide the population and dwelling counts for smaller geographic units such as cities or districts within cities. The census also provides information about Canada's demographic, social and economic characteristics. Census subdivisions were used as they account for municipality characteristics. Data were compiled on average household income for both 1991 and 1996.

3.5.4 Merging of Databases

Upon completion of the compilation of all the data, one merged database was formed. Using ArcView 3.2®, databases were joined using census sub-division codes as common fields within each individual dataset. Municipalities were screened to ensure that all fields were filled, and, if a field was left vacant in the source database, the municipality was deleted from the merged database. Sample sizes varied somewhat across the study period (Table 10).

Table 10: Number of Municipalities within Each Database for Region of Study.

Region	Year	Number of municipalities in sample
Ontario	1989	267
	1991	384
	1994	371
	1996	362
	1999	339
Prairies	1989	111
	1991	250
	1994	264
	1996	260
	1999	251

With respect to the summer precipitation data, the centroidal points of the municipalities were associated to the closest meteorological station for which data were collected. This was accomplished by assigning data to a location (spatial join function). A spatial join is based on the spatial relationship between the features in the two themes (in this case the centre coordinates of the municipalities and the meteorological stations coordinates, both point themes). For each feature represented in the destination table, ArcView associates data from the source table. Distances between points are also added. This field is automatically calculated by ArcView®, and contains the distance to the nearest feature represented in the source table for each feature represented in the destination table.

3.6 Statistical Techniques[11]

This section discusses the techniques used in the production of the results presented in Chapter 4. It discusses correlation analysis, regression analysis and the tests

[11] The discussion of statistical techniques given here is a brief summary of a large field of statistical analysis. It concentrates only on the procedures used in this thesis, and is not intended as an authoritative discussion of the larger field. For the latter, the reader should refer to a statistics textbook.

linked to statistical significance. It is then followed by a discussion of the modelling procedures used throughout the study. It begins by defining each statistical technique, and is followed by applications of each technique to the current research. For the production of the statistical results of the thesis, the data were tested using the SPSS® software package.

3.6.1 Correlation Analysis

Pearson correlation analysis is a statistical technique that calculates the relation between two variables. A correlation coefficient is calculated by the following equation:

$$R=\frac{\frac{\Sigma(x-\bar{x})(y-\bar{y})}{n-1}}{\sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}\sqrt{\frac{\Sigma(y-\bar{y})^2}{n-1}}} \qquad \text{(Equation 3)}$$

Customarily, the degrees to which two or more independent variables are related to the dependent variable are expressed in the correlation coefficient “R”. In correlation analysis, R can assume values between -1 and 1. To interpret the direction of the relationship between variables, one looks at the signs (plus or minus) of the regression coefficients. The values the furthest from zero are found to be the most correlated, the sign representing the nature of the relationship. A negative sign designates an inversely proportionate relationship. A high value indicates that both variables fluctuate in the same order of magnitude. With correlation analysis, one must also analyse the significance level of the relationship between variables.

Correlation analysis is done prior to regression analysis to ensure that the independent variables being used are not themselves strongly related – that is, to avoid "multicollinearity" problems[12]. Should the latter be true, using both related variables in a regression analysis will produce biased results, in the sense that individual accounts of "explanation" from different independent variables will be biased as these would account for the same variations in the dependent variable. In a systematic correlation analysis, each independent variable is correlated with each of the others being used, even though it may be quite clear that the variables are not related – for example, here, water price and precipitation. In this research, R values above 0.5 were considered to indicate substantial correlation between two variables. Thus, if two independent variables had R values > 0.5, one was eliminated from the subsequent regression analysis. Statistical significance on the correlation analysis was also reported and variables that were deemed statistically significant by the correlation analysis were not included in the final models[13].

Correlation analysis data presented in Tables 11 and 12 are for the year 1991 only. 1991 was selected because data on household income were available only for census years. The correlation analysis was carried out for year 1996 as well, but is not presented here because the results were essentially the same as for 1991. Correlation values indicated that marginal price, total price, and the dummy variables for price structure were highly correlated. (Tables 11 and 12), which is to be expected. Areas in grey are deemed to be significantly correlated.

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[12] Multicollinearity is defined as the inclusion in a regression model of two closely inter-related (or correlated) variables.

[13] A description of statistical significance can be found in section 3.6.3.

Table 11: Correlation Coefficients Between Independent Variables for Ontario, 1991.

Variable[1]	Price Structure	Marginal Price	Total Price	Summer Precipitation	Density	Income
Price Structure	1	0.808 0.000	0.524 0.000	-0.183 0.110	0.077 0.133	0.255 0.070
Marginal Price		1	0.724 0.000	-0.142 0.095	0.075 0.145	0.278 0.098
Total Price			1	-0.139 0.087	-0.032 0.530	0.096 0.061
Summer Precipitation				1	0.003 0.949	-0.076 0.137
Density					1	-0.100 0.050
Income	Where N = 384					1

[1] The top numbers in each of the variable rows represent the Pearson correlation coefficients while bottom ones quantify the significance levels of the relationship using a t-test (to be explained within section 3.6.3).

Table 12: Correlation Coefficients Between Independent Variables for the Prairie Provinces, 1991.

Variable[1]	Price Structure	Marginal Price	Total Price	Summer Precipitation	Density	Income
Price Structure	1	0.688 0.000	0.508 0.000	-0.028 0.655	0.103 0.103	-0.088 0.166
Marginal Price		1	0.814 0.000	0.021 0.746	-0.014 0.830	0.018 0.777
Total Price			1	-0.073 0.254	-0.08 0.206	0.120 0.058
Summer Precipitation				1	0.068 0.286	-0.087 0.172
Density					1	-0.028 0.661
Income	Where N = 250					1

[1] The top numbers in each of the variable rows represent the Pearson correlation coefficients while bottom ones quantify the significance levels of the relationship using a t-test (to be explained within section 3.6.3).

Tables 11 and 12 indicate significant correlations between the two price variables, as well as between the dummy variable representing price structure. In the regression analyses, marginal price was used as the independent variable, largely because economic theory suggests that this is the most important price variable used in purchasing goods and services. Total price results were also included for comparative purposes To eliminate the high correlation between price structure and marginal price, the regression models were run twice – first using the entire dataset, and the using only the volumetric dataset. An additional reason for undertaking this division is that customers faced with flat rate pricing do not react to pricing changes because usage levels are unaffected by prices.

A second correlation analysis was then undertaken using only volumetric data with marginal price as the price variable (although total price was also tested and similar high correlations between the price variables were found). Correlation coefficients are found in Tables 13 and 14 for both Ontario and the Prairie Provinces. Again, the year 1991 was used to report these coefficients. Similar coefficients were found within other databases with no significant correlations between data, although the R values may vary slightly.

Table 13: Correlation Coefficients Between Independent Variables for Ontario Within the Volumetric Sub-Set, 1991.

Variable[1]	Marginal Price	Summer Precipitation	Density	Income
Marginal Price	1	-0.009 0.896	0.059 0.386	0.096 0.161
Summer Precipitation		1	0.064 0.365	-0.015 0.824
Density			1	-0.138 0.059
Income	Where N = 202			1

[1] The top numbers in each of the variable rows represent the Pearson correlation coefficients while bottom ones quantify the significance levels of the relationship using a t-test (to be explained within section 3.6.3).

Table 14: Correlation Coefficients Between Independent Variables for the Prairie Provinces Within the Volumetric Sub-Set, 1991.

Variable	Marginal Price	Summer Precipitation	Density	Income
Marginal Price	1	0.063 0.391	-0.136 0.062	0.131 0.071
Summer Precipitation		1	0.068 0.354	-0.072 0.329
Density			1	-0.005 0.950
Income	Where N = 189			1

1 The top numbers in each of the variable rows represent the Pearson correlation coefficients while bottom ones quantify the significance levels of the relationship using a t-test (to be explained within section 3.6.3).

3.6.2 Regression Analysis

Regression analysis is a statistical test that allows the drawing of relationships between one dependent variable and a group of independent (or explanatory) variables. Regression is used to determine what variables contribute to the explanation of the dependent variable and to what degree. The independent variables can predict the dependent variable, but the dependent variable cannot be used to predict the independent variables. It is a one-way analysis. This technique permits the testing of hypotheses of the relationships between the former and the latter. A regression equation format was used in section 3.2 already to specify the nature of the variables used in this research. More generally these types of models take the following form:

$$Y = f(x_1, x_2, x_3, \ldots, x_n) \qquad \text{(Equation 4)}$$

Where:

Y = the dependent variable;
x_n = the independent variables.

This general form is then converted to a mathematically testable form, as follows:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + \ldots + b_nx_n + e \qquad \text{(Equation 5)}$$

Where:

e = the error term, or residual, of the equation

The output of a regression analysis include, for example within linear regression analysis, the parameters necessary in the creation of a linear curve, $y = a + bx$, where b is the slope and a is the y-intercept, as well as a coefficient of determination (R^2), a F statistic, and several other diagnostic measures. The coefficient of determination is the squared value of the correlation analysis results (R) outlined above. The R^2 values indicate how much of the total variance is "explained" by variation in the independent variable(s); the F statistic measures the overall goodness of fit of the equation.

The TRWD regression model used logarithmically transformed population data, in the present case using natural logarithms. There are two advantages to transforming data in this manner. First, for water demand, the price-quantity relationship tends to be curvilinear, for reasons suggested by Grima (1972) and Al-Qunaibet and Johnston (1985). Because linear regression analysis, by definition, requires linearity, it becomes necessary to transform the data into a form as close to linear as possible. Logarithmic transformations accomplish this. This issue was dealt with above. At the same time, such transformations ameliorate the effect of extreme values (e.g., large municipalities) on the dataset, by, in effect, making the dataset more "compact." In other words, logarithmic transformations consolidate the dataset, such that the analysis is not biased by larger values. This second advantage overcomes the need for dividing the samples into population size groups. In this case, the regression equations became exponential.

Another type of regression analysis was undertaken for the dummy variable. A coefficient of correlation between a binary variable and a continuous variable is called the point biserial correlation coefficient. The point biserial correlation coefficient, symbolized as R_{pb}, is used in the case where one variable is dichotomous and the other is non-dichotomous.

The concept of the point biserial correlation coefficient is based on a rendering of the coefficient of correlation as a slope of a regression line. For each category of a binary predictor variable, the predicted score can be calculated by the regression on categories method as a mean of the scores in either 0 or 1 category.

3.6.3 Significance Statistic Testing: The F Test and the t-test

In a simple regression, the F statistic is used to test whether the slope coefficients obtained through regression analyses are different from zero. F is calculated by dividing the difference of the sample mean by the variation within the sample itself. F is large when the independent variable helps to explain substantial variations in the dependent variable. F significance is derived from both the F values and the degrees of freedom within the regression analysis.

Accordingly, F significance is derived from a table similar to one of Student's type. Within simple regression, the F significance is identical to the t-test significance.

For multiple regression, the F values characterizes the significance of the entire (with all independent variables) relationship. In reality, it is the F significance that quantifies this significance and is derived from the F value, the degrees of freedom as well as the number of independent variables in the multiple regression analysis.

In order, to identify whether a specific variable is significant within the multiple regression model, one must look at the t-test (and accordingly the significance). The t-test is calculated by dividing the coefficient found within the regression analysis by the standard error. For the purposes of the thesis, significance is defined by all relationships significant to the 95% level, i.e. with significance values lower than 0.05.

3.6.4 Modeling Procedures

The functional forms of the two models used were specified in section 3.2. To recapitulate, these are:

$$\text{TRWD} = f\,(\text{Pop, PS, P, I, SP}) \qquad \text{(Equation 1)}$$

$$\text{RWD/cap} = f\,(\text{PS, P, I, SP, D}) \qquad \text{(Equation 2)}$$

Where the variables are as specified earlier.

To be used in the regression analysis, these models must be formulated in more precise mathematical terms. At the same time, the precise regression procedures used must be outlined.

Within the thesis, the models described below where run on municipalities using volumetric-based pricing only. As hypothesised earlier, price should act as a predictor of water demand, but only within municipalities where pricing varies with usage. An additional analysis was undertaken for price structure and this variable needs to be measured on the entire datasets (all municipalities: flat rates = 0, and volumetric rates = 1). Price structure is, therefore, not included in the mathematical models presented below.

a. Total Residential Water Demand Model

Equation 1 can be stated in a mathematically testable form as follows:

$$\text{TRWD} = a_1 + b_1\text{Pop} + b_2\text{P} + b_3\text{I} + b_4\text{SP} + e \qquad \text{(Equation 6)}$$

Where all variables are as defined earlier.

The regression analysis proceeded in several steps. First, to obtain an initial indication of the importance of each independent variable in "explaining" the variations in TRWD, simple regressions were run for each variable. This produced an indication of which variables were likely to be important is explaining the variance in TRWD. In these simple regression runs, the log-transformed population data were used, for reasons given above, and both price variables, total and marginal, were run. Second, the multi-variable model specified in Equation 6 was run to determine how successful the multi-variable model was the explaining the variation of the dependent variable. In this multiple model, it is possible that some of the independent variables will be insignificant. Thus, the model was rerun, eliminating variables that were determined to be insignificant. Finally, an optimized model was produced that contained only the statistically significant variables, in order to produce the most "efficient" equation possible.

One additional factor was important in running the TRWD model. The municipal population dataset, as shown earlier, contains information on a relatively large number of small communities, and a relatively small number of large ones. Using the raw data in regression analyses tends to bias the results towards the latter. Basically, this is because the regression procedure acts to minimize the error sum of squares, and this is accomplished by calculating a regression line that, in relative terms, passes nearer to the large communities than to the small ones. Also, the distribution of municipal population against water demand tends to be curvilinear (upwards to the right in a graph). Both of these problems can be addressed by logarithmically transforming the population data. However, this introduces an additional problem. Log transformations cannot be used on some of the other data, and it is not proper to use logged and unlogged data in the same regression equation. For these reasons, the log-transformed population data were used only when municipal population formed the only independent variable (i.e., in simple regression). In all other cases, the unlogged data were used. Finally, the price variable in all multiple regression analyses was marginal, not total, price of water. This avoided the multicollinearity problem described earlier in the chapter.

b. Residential Water Use per Capita Model

Equation 2 can be stated in a mathematically testable form as follows:

$$RWD/cap = a_2 + b_2P + b_3I + b_4SP + b_6D \qquad \text{(Equation 7)}$$

Firstly, several steps were needed to perform the regression analysis. As for the TRWD model, a series of simple linear regression analyses were run. Following these initial regression results, the model including all the variables mentioned in Equation 7 was run. Again, it is possible that some of the independent variables will be insignificant. As for the TRWD model, insignificant independent variables were taken out of the initial model presented in Equation 7 and the model was optimized. Within the RWD/cap model both price variables were tested. Marginal price was however chosen within the final model.

3.7 Time Series and Cross-Sectional Data

Time series data, as the term implies, is a collection of data that applies to a particular issue through time, such as the data used in this research. They represent measurements of the same variable (e.g., marginal price) across a certain time period, in this case from 1989 to 1999. Cross-section data pertain to measurements across space, for example among a set of municipalities. When cross sectional and time series data are pooled, as they were in this research, and used in a regression analysis, the results are more robust than just using, for example, data for one year. One possible problem that can arise in pooling time series data is that of serial, or auto-correlation, which indicates that a variable's value in year t might be correlated with its value in year t-1. To test for this, the Durban-Watson test was used. No autocorrelation was found, thus making the pooling of the data without adjustment permissible.

CHAPTER IV

Patterns of Residential Water Demand: Analytical Results

This chapter presents the results of the analysis. It begins with a statistical description of total and per capita water demand patterns, first in Ontario and then in the Prairie provinces following Schaefer and Hurst (1997) in terms of reporting structure. Contrasts between patterns of usage will emerge from this discussion. The focus then turns to a presentation of the regression analysis results. The combination of these two major sections will allow for the formulation of conclusions as to the importance of the various independent variables discussed in Chapter 2, using the techniques outlined in Chapter 3, in explaining the levels of total and per capita water demands.

4.1 Descriptive Statistics for Ontario

4.1.1 Survey Response

In 1989, 265 municipalities responded to the water use and pricing survey representing approximately 78% of Ontario's total population. Although there were slight variations in intervening years (Table 15)[14], this percentage was generally stable throughout the survey years with a 1999 value of 78%. Small[15] and large[16] municipalities were well represented, across all years, providing robust samples of water pricing practices in use. In general, the survey response rate was high and it seems reasonable to assume that the surveys represent well the water pricing practices used within Ontario during the decade of study.

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[14] These numbers include municipalities for which responses to the Municipal Water Use Survey and the Municipal Water Pricing Survey were received.

[15] Under 10,000 in population served by water supply services.

[16] Over 10,000 in population served by water supply services.

Table 15: Ontario Water Use and Pricing Databases - Number of Respondent Municipalities and Population Served by Water Supply (1989 to 1999).

Survey Year	Municipalities Under 10,000 Persons[1]	Municipalities Over 10,000 Persons[1]	Municipalities with Volumetric-Based Pricing	Survey Total	Total Regional Population[2]
1989	165 (692)	100 (7,965)	153 (4,848)	265 (7,650)	9,782
1991	262 (1,013)	122 (8,028)	202 (5,877)	384 (8,094)	10,085
1994	258 (947)	113 (8,334)	214 (6,218)	371 (8,243)	10,387
1996	245 (931)	117 (8,665)	216 (6,717)	362 (8,524)	10,754
1999	202 (1,192)	136 (8,629)	208 (6.973)	339 (9,239)	11,874

Source: Based on Environment Canada MUD database for respective years.
[1] Number of municipalities and (total population in thousands).
[2] In thousands of persons.

4.1.2 Level of Servicing

Approximately 7.6 million individuals received water from public supplies in 1989. This number grew to 9.2 million for 1999, a 21% increase. This increase was identical to the total provincial population increase for the same period of time. Figure 9 indicates consistent patterns, whereby the number of persons serviced from water supplies grew in nearly constant proportion to total population.

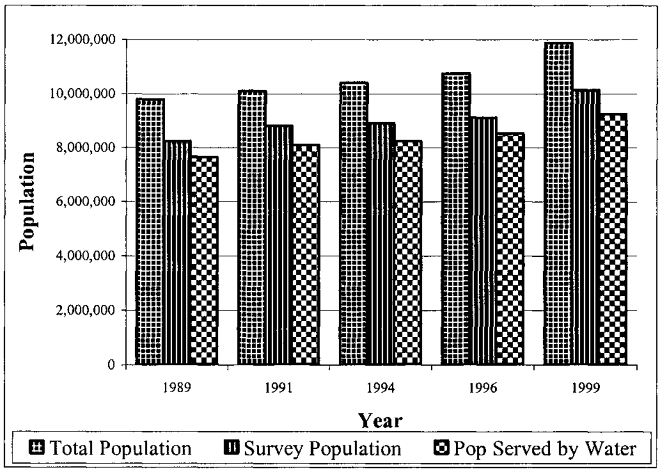

Figure 9: Ontario Population Served by Water Supply (1989-1999).

The mean population served by water services value was of 41,466, all years combined (Table 16). These population values vary quite importantly throughout the different sample years, as standard deviation values are high. The bulk of the municipalities have low population served by water services value, as smaller municipalities outnumber the number of larger ones within the survey. This can be seen by the median values varying from 5,033 to 7,000 throughout the various sample years.

Table 16: Descriptive Statistics on Population Served by Water Services for Ontario.

Population Served by Water Services

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	36,699	7,000	1,011	92,000	88,925
1991	28,514	5,802	864	73,000	77,117
1994	39,564	5,033	1,170	71,650	82,975
1996	31,929	5,400	1,220	74,078	31,929
1999	83,333	6,758	1,300	82,838	366,252
All	41,466	5,895	1,200	82,000	180,138
Source: Based on Environment Canada MUD databases for respective years.					

4.1.3 Water Demand

Water demand trends are divided into two categories for the purposes of the purposes of this study: Total water demand (TWD) and total residential water demand (TRWD) (Figure 10). Through the ten-year period the TWD grew from approximately 4.6 million cubic meters (m^3) per day to just over 5 million m^3 per day (a 9% increase). The values for TWD stayed fairly constant for the first three survey years and then rose more sharply in the two last survey years (1996,1999).

The TRWD values displayed the same trends, increasing from 2.1 million m^3 per day (1989) to 2.7 million m^3 per day (1999) through the time period of study. The level of TRWD was fairly constant for the first three sample years, but grew faster between 1996 and 1999. Overall, during the ten-year period TRWD grew by 29%. Within Ontario municipalities TRWD values averaged 11,220m^3/day (Table 17). The median, however, was significantly lower, at 2,100m^3/day, representing the high number of small municipalities in the surveys.

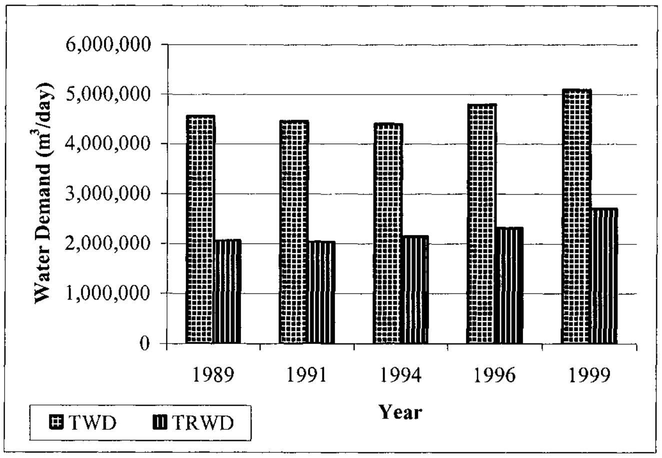

Figure 10: Total Water Demand for Ontario Municipalities (1989-1999).
Source: Based on Environment Canada MUD databases for respective years.

With the 21% increase in population combined with the growth of 9% for TWD, per capita residential water demand values generally decreased over the decade of study. The total water demand per capita (TWD/cap) values decreased by 8%, from 0.6m^3/day to 0.55m^3/day. The average value for all survey years was 0.56m^3/day (Figure 11).

Residential water demand per capita (RWD/cap) for the combined samples of municipalities fell from 0.41m^3/day to 0.26m^3/day over the decade. The average RWD/cap value over the time period was 0.35m^3/day (Table 17). Standard deviation was however quite high (0.21) for the entire time period, representing the large degree of variations of RWD/cap throughout the region. A strong decrease was apparent in RWD/cap between 1996 and 1999. It is also noteworthy that the percentage of residential water demand to total water demand decreased; that is, residential water demand became a smaller portion of the total water demand budget within the municipality.

Table 17: Descriptive Statistics on TRWD and RWD/cap for Ontario.

TRWD (m^3/day)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	10,269	2,764	336	26,894	24,127
1991	7,835	1,986	407	20,600	17,210
1994	7,961	1,777	432	20,273	20,616
1996	8,813	1,909	418	20,333	24,464
1999	22,010	2,467	472	21,450	89,647
All	11,220	2,100	410	20,144	11,220

RWD/cap (m^3/day)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	0.41	0.33	0.16	0.73	0.33
1991	0.39	0.35	0.19	0.62	0.19
1994	0.36	0.34	0.19	0.55	0.16
1996	0.35	0.32	0.20	0.54	0.15
1999	0.26	0.22	0.09	0.46	0.18
All	0.35	0.31	0.19	0.58	0.21
Source: Based on Environment Canada MUD databases for respective years.					

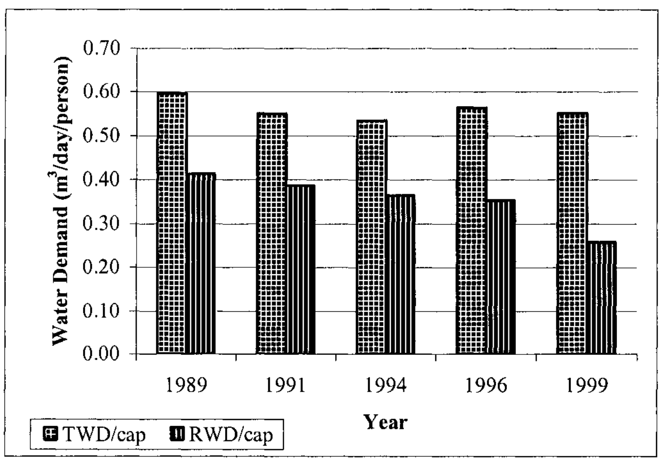

Figure 11: Total Per Capita Water Demand per Capita for Ontario Municipalities (1989-1999). Source: Based on Environment Canada MUD databases for respective years.

4.1.4 Water Supply Sources

Water supply sources within Ontario fall within three broad categories: surface water, groundwater and a combination of both (Figure 12). Throughout the study period, the overall percentage of water supplied from surface water showed only a slight increase. This increase was offset by an apparent general decrease in the use of combined water sources, which in turn implied a reduction of supply from groundwater sources. While the level of intake derived from groundwater may appear low, it should be remembered that the volume of intake from groundwater sources, recorded in the MUD database, only did not include persons with private wells, and that groundwater usage was mostly in smaller communities. The larger municipalities almost always had surface water supplies[17].

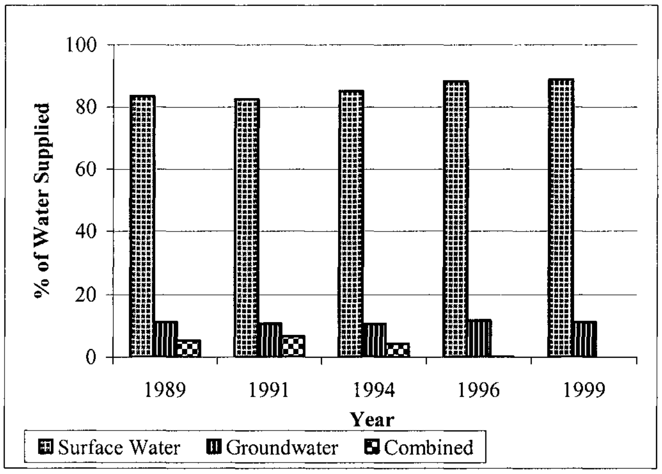

Figure 12: Water Supply Sources by Population Served by Water for Ontario (1989-1999). Source: Based on Environment Canada MUD databases for respective years.

4.1.5 Rate Schedules

Municipalities with flat rate pricing in Ontario accounted for approximately 40% of the total throughout the study period, the remaining 60% of municipalities used volumetric-based pricing structures (Figure 13). Within the municipalities using volumetric-based pricing, approximately 50% employed the constant unit charge system. The remaining rate structures were divided into decreasing (40%) and increasing (10%) block rate systems. The data indicated that a slight overall shift away from the use of flat

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[17] However, it should be noted that the regional municipality of Waterloo (with a total population of 78,000 in 1999) was almost entirely served from groundwater supplies.

rate towards volumetric-based pricing occurred between 1989 and 1999. This trend resulted in a decrease in 4% from the initial 42% use of flat rate pricing.

As outlined in Chapter 2, a flat-rate charging system provides no incentives of water conservation because the marginal cost is effectively zero. Therefore, a shift from the flat-rate charges to volumetric is viewed as progress towards water conservation. In addition, within the volumetric rates, a DBR is the least water conserving of the pricing structures, because the marginal cost falls throughout the blocks of the rate schedule used. A decrease within this pricing system also occurred during the study period. The use of CUC and the IBR grew throughout the study period. Hence, there appears to have been a small tendency towards conservation-oriented rate systems.

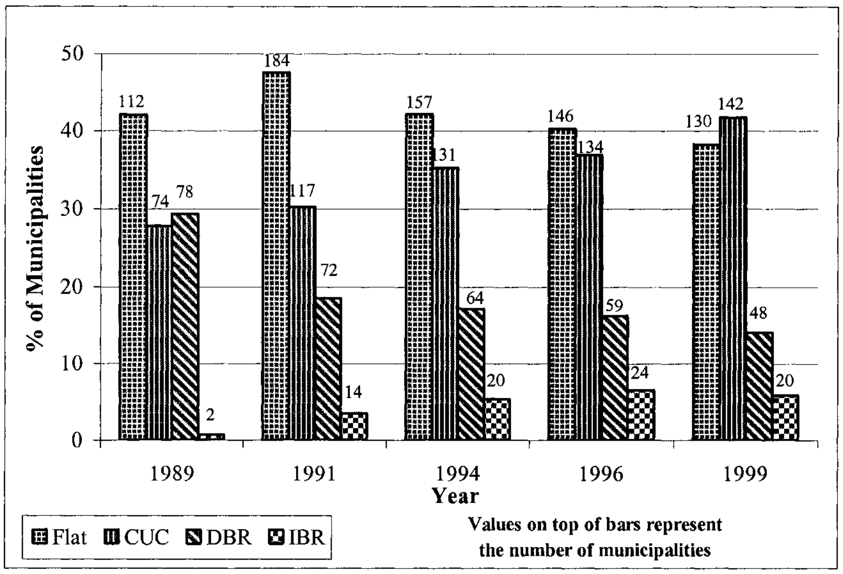


Figure 13: Percentages and Numbers of Rate Structures within Ontario Municipalities (1989-1999). Source: Based on Environment Canada MUD databases for respective years.

All municipalities showed steadily declining RWD/capita throughout the period, decreasing from $0.38m^3$/day to $0.22m^3$/day for volumetric structures; $0.46m^3$/day to $0.31m^3$/day for flat rates (Table 18). These changes in demand reflect a 21% to 41% decrease of RWD/capita for municipalities with volumetric-based pricing structures. In addition, although not shown here, the differences in rate structures, for RWD/capita, are minimal for the three types of volumetric-based pricing. Overall, we can observe a substantial decrease in RWD/cap.

Table 18: Variations of Price Values and Residential Water Demand per Capita for Flat Rate and Volumetric Pricing Structures.

Survey year	Volumetric			Flat			All		
	Price[1] of $35m^3$	RWD/cap (m^3/day/ person)	Number of Muni.	Price of $35m^3$	RWD/cap (m^3/day/ person)	Number of Muni.	Price of $35m^3$	RWD/cap (m^3/day/ person)	Number of Muni.
1989	27.45	0.38	154	17.33	0.46	112	23.17	0.41	266
1991	33.83	0.35	203	21.02	0.43	184	27.76	0.39	387
1994	39.60	0.33	215	24.84	0.42	157	33.37	0.36	372
1996	42.87	0.31	217	29.24	0.42	146	37.37	0.35	363
1999	44.86	0.22	210	32.79	0.31	130	40.24	0.26	340

Source: Based on Environment Canada MUP and MUD databases for respective years.
[1] All prices corrected to constant price values.

4.1.6 Water Prices

As outlined in Table 19, the real[18] price of water increased through time from \$23.17 (in 1989) to \$40.24 (in 1999) with all rates schedules taken into account. Flat-rate prices were consistently lower than the volumetric-based ones, not only on average, but also when considering the individual pricing structures (Figure 14). The prices shown in this section were for total prices and the marginal prices at the $35m^3$/month level. The marginal prices also increased in real terms.

[18] All prices corrected to 1992 constant value using the Consumer Price Index (CPI) for water services.

Table 19: Descriptive Statistics on Marginal and Total Price for Ontario.

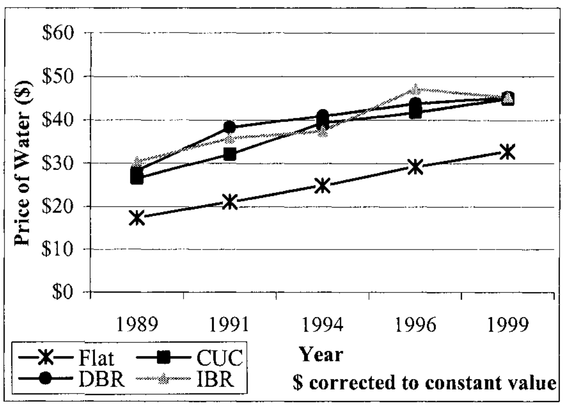
Marginal Price ($)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	$0.34	$0.27	$0.00	$0.88	$0.36
1991	$0.39	$0.24	$0.00	$1.01	$0.46
1994	$0.50	$0.42	$0.00	$1.27	$0.53
1996	$0.56	$0.54	$0.00	$1.33	$0.56
1999	$0.63	$0.64	$0.00	$1.41	$0.63
All	$0.49	$0.40	$0.00	$1.20	$0.53

Total Price ($)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	$23.17	$21.57	$10.74	$37.69	$10.72
1991	$27.76	$26.47	$13.73	$44.78	$12.21
1994	$33.37	$31.37	$15.53	$54.59	$14.72
1996	$37.37	$36.15	$18.36	$56.78	$15.47
1999	$40.24	$37.25	$28.42	$63.18	$17.38
All	$32.82	$30.67	$21.15	$52.41	$15.55

Source: Based on Environment Canada MUD databases for respective years.



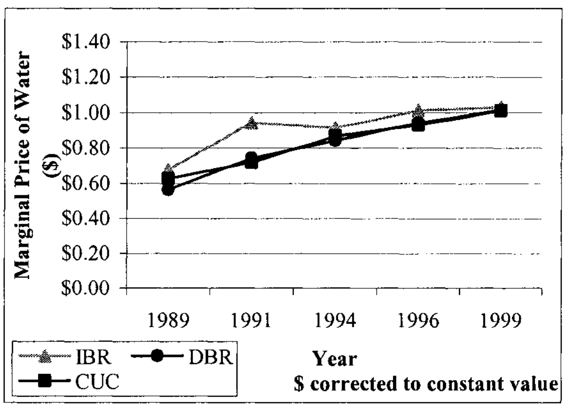


Figure 14: Variations of Price for Water in Ontario (1989-1999).

Source: Based on Environment Canada MUP databases for respective years.

4.1.7 Income

Average household income values were found to be approximately $51,318 within Ontario. These grew slightly between 1991 and 1996, from $48,421 to $54,399

(Table 20). Income values varied quite significantly between municipalities in the region as the 10^{th} percentile value was of $37,363 and the 90^{th} percentile of $68,143. The standard deviation value, for the entire dataset, was of $13,914.

Table 20: Descriptive Statistics on Income for Ontario.

Income ($)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	N.A.	N.A.	N.A.	N.A.	N.A.
1991	$48,421	$45,775	$35,828	$63,863	$12,460
1994	N.A.	N.A.	N.A.	N.A.	N.A.
1996	$54,399	$50,945	$39,917	$71,903	$14,481
1999	N.A.	N.A.	N.A.	N.A.	N.A.
All	$51,318	$48,869	$37,363	$68,143	$13,914
Source: Based on Statistics Canada census databases for respective years.					

4.1.8 Density

Density values varied throughout Ontario within the study period. The average value for this variable was 614 persons/km^2 for the pooled dataset. Median values were substantially lower than mean values with 304 persons/km^2, again within the pooled dataset (Table 21). Values grew, from 1989 to 1996, varying from 225 persons/km^2 to 431 persons/km^2 (Figure 15). This was followed by a sharp decrease in density values, as large municipalities within Ontario underwent amalgamation between these two years.

Table 21: Descriptive Statistics on Density for Ontario.

Density

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	775	225	18	2,026	893
1991	585	379	23	1,242	866
1994	775	407	16	1,397	833
1996	602	431	26	1,268	863
1999	382	78	13	1,054	677
All	614	304	24	1,250	609
Source: Based on Environment Canada MUD databases and Statistics Canada Census databases for respective years.					

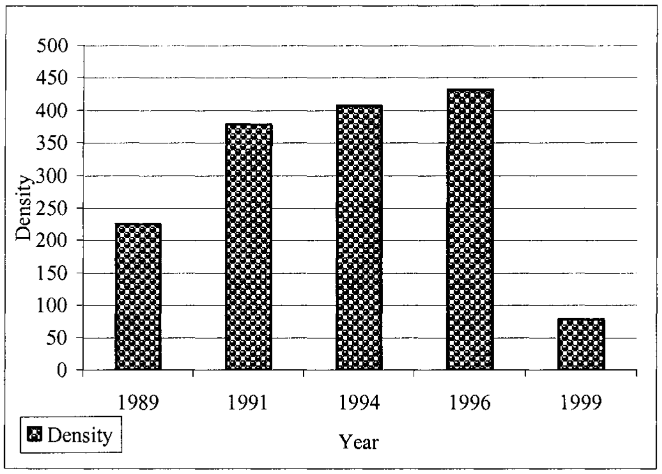


Figure 15: Median Density Values for Ontario, from 1989 to 1999.

Source: Based on Environment Canada MUD databases and Statistics Canada Census databases for respective years.

4.1.9 Rainfall

Average rainfall values varied from 248mm to 373mm for the summer months of the period at study (Figure 16). The years of 1989 and 1991 were slightly drier than those that followed. While the two earliest years had values ranging between 248mm and 276mm, the latter years had values over 350mm. The average value for the pooled dataset was of 328mm. Standard deviation values were fairly consistent throughout the years with values ranging from 67mm to 84mm (Table 22).

Table 22: Descriptive Statistics on Rainfall for Ontario.

			Rainfall (mm)		
Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	276	282	202	366	67
1991	248	239	175	333	67
1994	366	363	267	469	76
1996	368	365	268	474	77
1999	373	369	281	488	84
All	328	323	202	443	92
Source: Based on Environment Canada climate databases for respective years.					

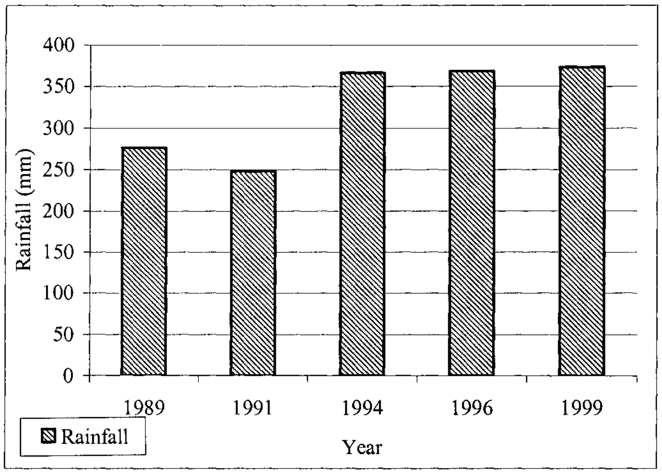


Figure 16: Average Summer Precipitation Values for Ontario, from 1989 to 1999.
Source: Based on Environment Canada climate databases for respective years.

4.2 Descriptive Statistics for the Prairies, Including Comparisons With Ontario

4.2.1 Survey Response

The number of municipalities in the MUD surveys for the Prairie region rose from 111 (1989) to 251 (1999) (Table 23). There were slightly more responding municipalities in the intervening years than in 1999. On average, the surveys represented 72% of total regional population, a percentage that increased throughout the years, from 62% in 1989, to 75% in 1999. Number of small municipalities responding to the MUD survey increased throughout the sample period. The number of small communities surveyed rose substantially, especially between 1989 and 1991. A small increase also occurred in the number of larger municipalities surveyed as well, because there were fewer of these throughout the region and because these municipalities were better able to respond to the surveys. These two factors accounted for much of the observed increases in regional population included in the study. The percentage of individuals serviced by volumetric-based pricing in the region was quite high, over 90%. In summary, the survey response was high, in terms of total population, and therefore considered to represent well the region's water demand/water pricing variations throughout the time period, although, again, this was not a "scientifically selected" statistical sample. The proportions of population surveyed to total regional population were generally similar for the two regions: the values for Ontario around 78% and for the Prairies around 73%.

Table 23: Prairies Water Use and Pricing Databases - Number of Respondent Municipalities and Population Served by Water Supply (1989 to 1999).

Survey Year	Municipalities Under 10,000 Persons[1]	Municipalities Over 10,000 Persons	Municipalities with Volumetric-Based Pricing	Survey Total	Total Regional Population
1989	85 (480)	26 (2,321)	88 (2,682)	111 (2,802)	4,501,505
1991	224 (675)	26 (2,706)	190 (3,332)	253 (3,381)	4,626,423
1994	235 (695)	29 (2,816)	213 (2,984)	264 (3,511)	4,725,997
1996	231 (708)	29 (2,885)	213 (3,054)	260 (3,593)	4,800,961
1999	217 (653)	34 (3,095)	210 (3,187)	251 (3,749)	4,986,363

Source: Based on Environment Canada MUD database for respective years.
[1] Number of municipalities and (total population in thousands).
[2] In thousands of persons.

4.2.2 Level of Servicing

In the Prairie region, approximately 2.8 million persons were serviced by public water supplies in 1989 (Figure 17). This value grew (in part because the sample size grew) by 32% to 3.7 million persons in 1999. Within the time period studied the population of the Prairie Provinces increased by just over 11%. These data indicate a relative increase in the proportion of total regional population served by public water supplies.

The proportion of population surveyed to population served by water services was very high throughout the study period, as shown in Figure 17[19]. The consistency in this ratio indicates that the variation within the values for 1989, when compared to other

[19] In most cases, when a centralized communal water system is in place the majority of residents are served. Ever persons in the peri-urban area, but outside the boundary of the municipality may be served from public systems.

sample years, was due to lower numbers of municipalities surveyed in 1989 and not a significant change in the number of persons connected to water services.

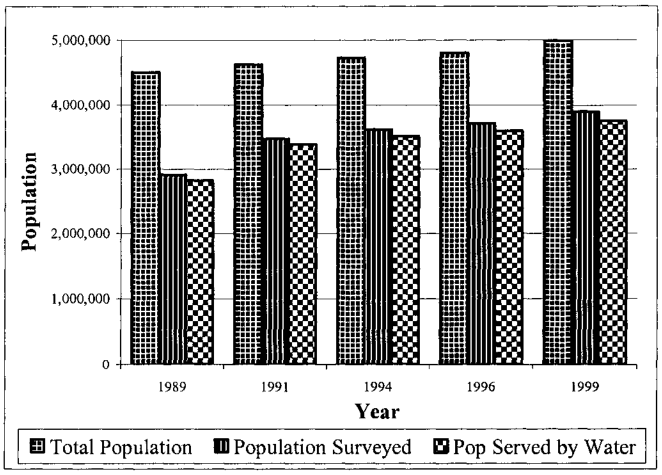


Figure 17: Prairies Population Served by Water Supply (1989-1999).

The mean population value, for individual served by water services, within the municipalities was 15,963 (Table 24). As within Ontario, the median values are consistently lower than those of the mean. These median values varied from 2,481 to 5,590 while mean values vary from 13,858 and 28,076.

Table 24: Descriptive Statistics on Population Served by Water Services for the Prairies.

Population Served by Water Services

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	28,076	5,590	1,380	37,694	98,399
1991	13,936	2,481	1,048	10,149	71,541
1994	13,858	2,481	1,039	10,800	71,265
1996	14,403	2,523	1,050	11,038	73,544
1999	15,129	2,443	1,049	12,000	77,390
All	15,963	2,526	1,050	13,000	77,056

Source: Based on Environment Canada MUD databases for respective years.

The variations between Ontario and the Prairie Provinces in levels of servicing are interesting. The population growth was higher in Ontario, surpassing by close to 10% that of the Prairie Provinces. In contrast, the proportion of population serviced by water supply services over population surveyed was higher in the Prairie region than within Ontario.

4.2.3 Water Demand

The TWD and TRWD values varied somewhat within the decade of study, with the former varying more than the latter (Figure 18). From 1991 to 1999, TWD decreased from a higher value between 1991 and 1996, and then rebounded back to 1991 values by 1999. The values varied from 1.4 million cubic meters per day in 1989 (remembering the smaller sample size) to 1.7 million cubic meters a day for 1991/1999.

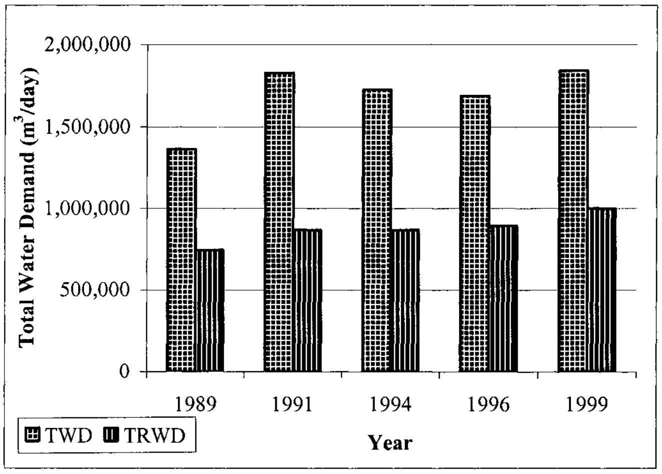


Figure 18: Total Water Demand for Prairie Municipalities (1989-1999).
Source: Based on Environment Canada MUD databases for respective years.

Conversely, the values for TRWD generally grew over the entire ten year period; the 1989 value being around 700,000 cubic meters per day increasing to one million cubic meters per day in 1999. From 1991 to 1996, TRWD increased very slightly. The overall growth was 42% (considering sample size differences). These values were somewhat higher than with the growth experienced by Ontario (29%). Average TRWD values within municipalities varied from 3,462 to 9,370. Variations, however, were quite large within the data as standard deviation values were high (Table 25).

Table 25: Descriptive Statistics on TRWD and RWD/cap for the Prairies.

TRWD (m^3/day)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	9,370	1,942	342	15,166	31,564
1991	3,672	795	282	3,410	16,390
1994	3,462	714	282	3,829	15,824
1996	3,625	814	305	4,311	17,388
1999	4,059	853	308	3,916	20,807
All	4,318	814	292	4,400	19,701

RWD/cap (m^3/day)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	0.35	0.29	0.18	0.67	0.22
1991	0.34	0.28	0.17	0.57	0.21
1994	0.32	0.29	0.18	0.49	0.16
1996	0.33	0.29	0.17	0.53	0.19
1999	0.34	0.30	0.18	0.52	0.18
All	0.33	0.29	0.18	0.53	0.19

Source: Based on Environment Canada MUD databases for respective years.

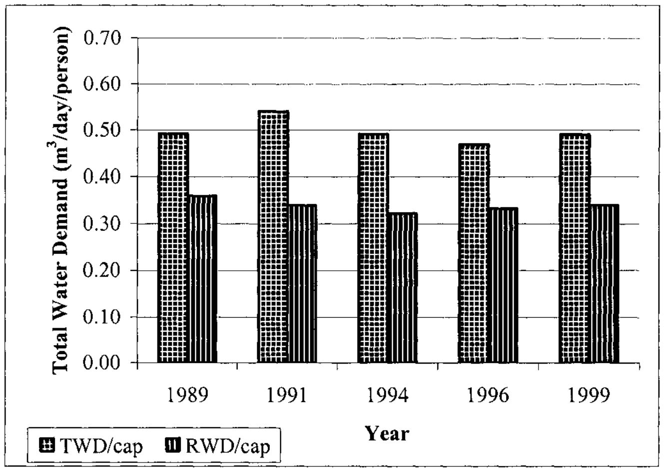


Figure 19: Total Per Capita Water Demand for Prairie Municipalities (1989-1999).
Source: Based on Environment Canada MUD databases for respective years.

Populations and total water use combine to show trends in per capita water demand (Figure 19). The values of TWD/cap in general decreased slightly from $0.55m^3$/day for 1991 to $0.49m^3$/day for 1999. A dip in 1996 produced a slightly lower value than in 1999. The overall decrease was 12%, higher than that experienced in Ontario. The average value over the study period was 0.50m^3/day. This value was marginally lower than in Ontario (0.56m^3/day).

The RWD/cap decreased slightly over the time period of study. These values ranged from 0.35m^3/day (1989) to 0.32m^3/day (1994) with the average value for the decade being 0.34m^3/day (Table 25). The variations throughout the years are therefore minimal, however standard deviation values are high. The variations of RWD/cap throughout time were not as substantial as in Ontario, but, again, the RWD/cap values were consistently lower within the Prairie region than in Ontario.

In contrast to the Ontario results, the ratio of residential water demand to total water demand showed an increase ranging from 45%, in 1989, to 52%, in 1999. Residential water demand therefore appeared to have become an increasingly important portion of the total water budget within municipalities.

4.2.4 Water Supply Sources

The three same supply sources pertain to the Prairie region as in Ontario (Figure 20). The proportion of intake of surface water within municipalities slightly increased through the study period. The decrease in the combined category of water supply offset this increase completely. This result indicated that municipalities using a combination of water sources moved towards surface water sources. Therefore, the number of municipalities using groundwater as their only source of intake remained constant through time and that the use of groundwater declined.

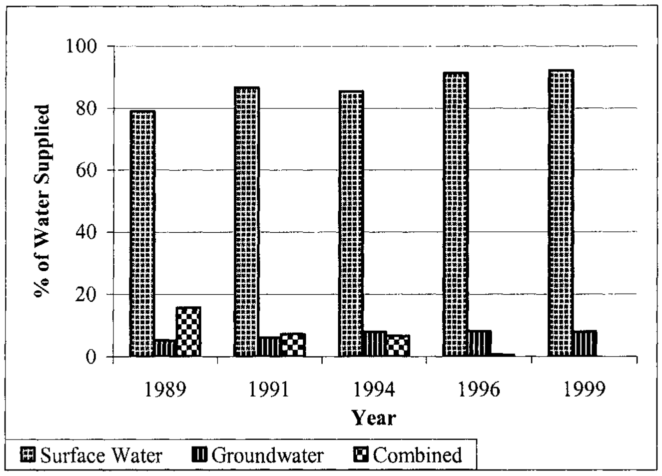


Figure 20: Water Supply Sources by Population Served by Water for the Prairies (1989-1999). Source: Based on Environment Canada MUD databases for respective years.

4.2.5 Rate Schedules

The first distinction necessary, when comparing water rate types between the two regions lies in the proportionately higher numbers of municipalities using volumetric pricing in the Prairies. Over the study period, on average, 80% of Prairies municipalities (Figure 20) employed this type of pricing structure with only 20% using flat rates. Recall that only 50% of Ontario municipalities used volumetric pricing.

Within the volumetric rates, approximately 50% of the municipalities used CUCs. IBRs accounted for 10% and DBRs the remaining 40%. This allocation within the volumetric subset was fairly consistent with the Ontario subset. The principal difference between the two regions was with respect to the apparent movement towards the use of CUCs in the Prairies. As the DBR rate type decreased overtime, with the municipalities switching to CUCs, a more conservation-based type of structure. The IBR proportion remained constant through the five individual survey periods.

The overall percentage decreases in the use of flat rates, with the corresponding shift towards volumetric pricing, are shown in Figure 21. The ratio of municipalities using flat rate charges was initially 25% in 1991 (notwithstanding 1989) and decreased to 16% by 1999. The shift away from the use of DBRs may also be viewed as a positive movement toward water conserving practices.

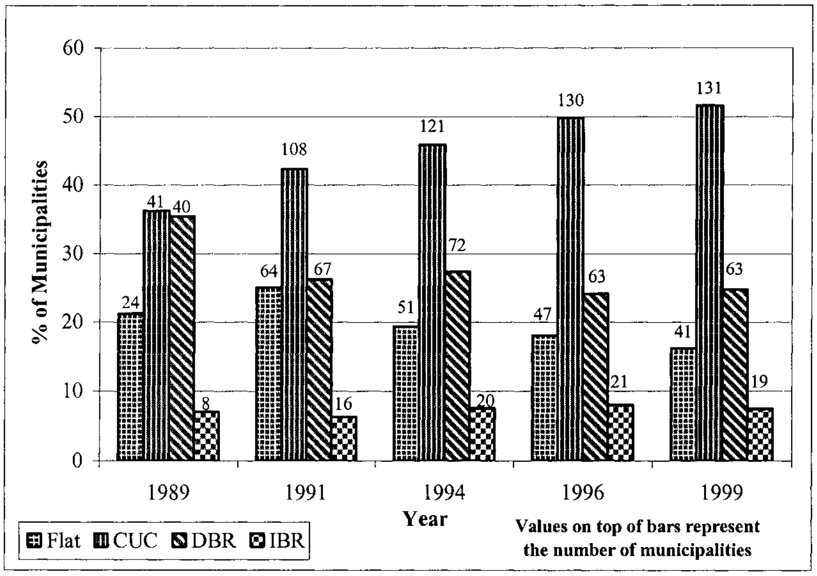


Figure 21: Percentages and Numbers of Rate Structures within Prairie Municipalities (1989-1999). Source: Based on Environment Canada MUD databases for respective years.

RWD/cap values varied with pricing structure (Table 26). Municipalities using flat rate pricing had RWD/cap values ranging from $0.42m^3$/day to $0.51m^3$/day. Values for municipalities with volumetric pricing systems varied from $0.30m^3$/day to $0.32m^3$/day.

Table 26: Variations of Price Values and Residential Water Demand per Capita for Flat Rate and Volumetric Pricing Structures within the Prairie Provinces.

Survey year	Volumetric			Flat			All		
	Price[1] of $35m^3$	RWD/capita (m^3/day/ person)	Number of Muni.	Price of $35m^3$	RWD/capita (m^3/day/ person)	Number of Muni.	Price of $35m^3$	RWD/capita (m^3/day/ person)	Number of Muni.
1989	35.99	0.32	89	20.32	0.51	24	32.74	0.36	113
1991	41.12	0.31	191	22.91	0.42	64	36.60	0.34	255
1994	45.48	0.30	213	26.21	0.42	51	41.76	0.32	264
1996	49.67	0.31	214	29.33	0.44	47	45.99	0.33	261
1999	52.72	0.31	213	32.22	0.48	41	49.40	0.34	254

Source: Based on Environment Canada MUP and MUD databases for respective years.
[1] All prices corrected to constant price values.

Also, real prices are substantially lower for the flat rate municipalities than the volumetric ones (from 25% to 37%).

4.2.6 Water Prices

The real price of water increased through time in the Prairies, as they did in Ontario (Table 27). Even with all rate structures combined, the prices still grew and by the same order of magnitude. Average prices, at the 35m^3/month level grew for the Prairies from $32.74 to $49.40 over the study period. Flat rate municipalities had lower water prices than volumetric ones (not only the general average but also within the three different pricing structures (Figure 21)). Marginal prices also increased through time.

Table 27: Descriptive Statistics on Marginal and Total Price for the Prairies.

Marginal Price ($)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	$0.63	$0.66	$0.00	$1.17	$0.50
1991	$0.66	$0.67	$0.00	$1.34	$0.55
1994	$0.78	$0.79	$0.00	$1.53	$0.58
1996	$0.87	$0.86	$0.00	$1.67	$0.63
1999	$0.94	$0.95	$0.00	$1.73	$0.63
All	$0.80	$0.78	$0.00	$1.58	$0.59

Total Price ($)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	$32.74	$32.55	$16.02	$51.83	$13.92
1991	$36.60	$36.00	$17.19	$55.46	$15.28
1994	$41.76	$41.96	$20.90	$62.08	$16.38
1996	$45.99	$44.88	$25.00	$67.16	$16.96
1999	$49.40	$48.63	$28.46	$74.64	$17.29
All	$42.54	$40.86	$21.21	$53.24	$17.01
Source: Based on Environment Canada MUD databases for respective years.					

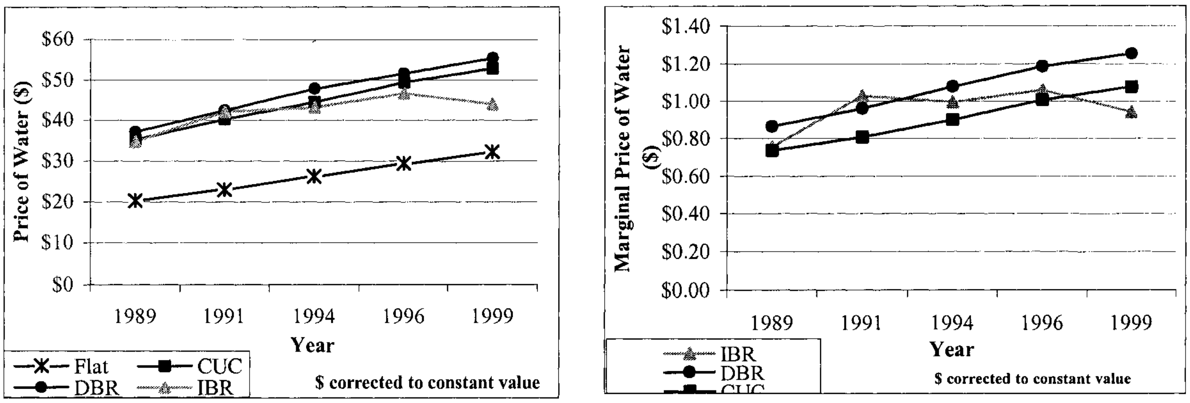


Figure 22: Variations of Price for Water in the Prairie Provinces (1989-1999).
Source: Based on Environment Canada MUP databases for respective years.

4.2.7 Income

Household income values averaged $43,723 for the Prairies during the years at study. The real income averages grew between 1991 and 1996, from $39,235 to 47,976. The 10th percentile value for household income was of $32,399, while the 90th percentile value was $56,904 (Table 28). Average household income values were slightly lower within the Prairie provinces than in Ontario.

Table 28: Descriptive Statistics on Income for the Prairies.

Income ($)

Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	N.A.	N.A.	N.A.	N.A.	N.A.
1991	$39,235	$37,849	$30,483	$49,944	$7,704
1994	N.A.	N.A.	N.A.	N.A.	N.A.
1996	$47,976	$47,116	$36,956	$60,646	$9,869
1999	N.A.	N.A.	N.A.	N.A.	N.A.
All	$43,723	$41,932	$32,399	$56,904	$9,971
Source: Based on Statistics Canada census databases for respective years.					

4.2.8 Density

Density values averaged 434 persons/km^2 for the pooled dataset (Table 29). Median values (Figure 23) varied from 330 persons/km^2 to 434 persons/km^2. Variations in density values were fairly small, with no particular time trends to be recognized.

Table 29: Descriptive Statistics on Density for the Prairies.

			Density		
Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	486	426	108	820	287
1991	448	421	107	783	277
1994	436	402	14	785	295
1996	338	330	1	750	359
1999	458	434	34	820	300
All	434	380	4	782	301
Source: Based on Environment Canada MUD databases and Statistics Canada Census databases for respective years.					

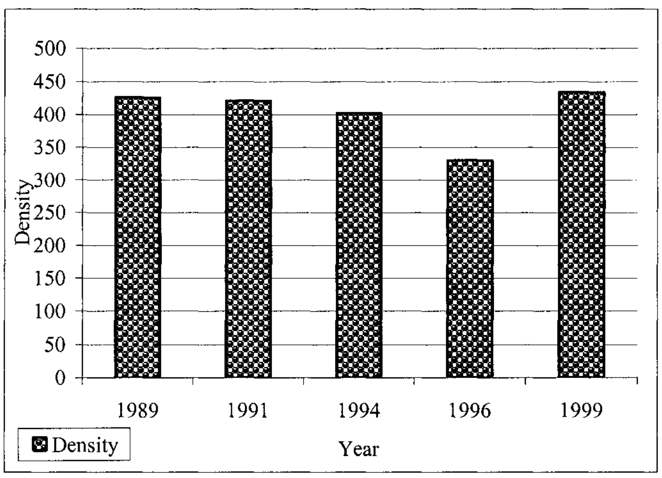


Figure 23: Median Density Values for the Prairies, from 1989 to 1999.

Source: Based on Environment Canada MUD databases and Statistics Canada Census databases for respective years.

4.2.9 Rainfall

The average rainfall value for the pooled dataset was of 277mm of precipitation for the summer months (Table 30). The values for rainfall were consistently lower within the Prairie region than in Ontario. The averages for individual years, in the Prairies, wee below 300mm, whereas the Ontario values were frequently above that mark (Figure 24). The 1989 and 1991 year show consistent patterns with the Ontario data, that is that precipitation values are lower than for the three latter years.

Table 30: Descriptive Statistics on Rainfall for the Prairies.

			Rainfall (mm)		
Year	Mean	Median	10th Percentile	90th Percentile	Standard Deviation
1989	247	248	154	333	76
1991	251	248	164	349	71
1994	298	298	173	417	89
1996	300	293	191	426	86
1999	267	266	170	360	79
All	277	267	171	391	84
Source: Based on Environment Canada climate databases for respective years.					

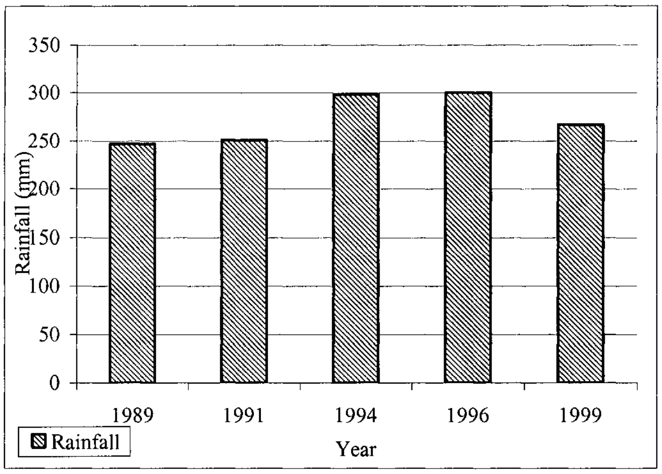


Figure 24: Average Summer Precipitation Values for the Prairies, from 1989 to 1999. Source: Based on Environment Canada climate databases for respective years.

4.3 TRWD Model

The TRWD model tested is represented as follows:

$$TRWD = a_1 + b_1Pop + b_2P + b_3I + b_4SP + e$$

Where all variables are as defined in Chapter 3.

The series of simple regressions run initially showed which of these variables were significant in accounting for the total variance in the dependent variable. Only those variables that proved to be statistically significant at the 95% level or greater[20] were included in the final model presented[21] (see Equation 8).

4.3.1 Analysis of Price Structure

Price structure was analysed using a dummy variable of 0 and 1 for flat versus volumetric based pricing mechanisms. As previously mentioned, this independent variable was run using the entire dataset for the regions. The coefficients of determination were very weak shown by R^2 values, varying from 0.002 to 0.005 (Table 31), but were nevertheless statistically significant. Both regions showed approximately the same values, but the coefficients for the slope and intercept varied greatly.

Table 31: Regression Results for the Price Structure with TRWD within all Municipalities.

TRWD = f (PS) - for all municipalities

Region	Intercept	Slope	R_{pb}[1]	R^2	t-test	Sig.	df
		PS					
Ontario	8114	5342	0.060	0.004	2.470	0.010	1721
Prairies	1499	3426	0.070	0.005	2.360	0.018	1140
All regions	6561	2857	0.040	0.002	1.950	0.050	2865

[1] Where R_{pb} is the Point Biserial Correlation Coefficient.

4.3.2 Analysis of Population

As outlined in section 3.6, values of population served by water services were transformed to logarithmic form for the simple regression analysis. Population served by water services was found to be a highly significant variable in explaining variations of

[20] Throughout this section, a level of significance of 95% or better was assumed to be acceptable in "explaining" variation in the dependent variable.
[21] This procedure is equivalent to using a step-wise regression procedure.

TRWD (Table 32). Coefficients of determination varied from 0.878 to 0.920 throughout the two regions. The significance levels, reflected in the F values, were also very high.

Table 32: Regression Values between TRWD and Population Served by Water Services (log) for Municipalities with Volumetric Pricing Schedules.

TRWD = f (Pop) - for all volumetric based pricing municipalities

Region	Coefficient	Slope	R^2	F	F Sig	df
		Pop				
Ontario	0.735	0.910	0.920	947.32	0.000	914
Prairies	0.367	0.976	0.878	1125.36	0.000	922
All regions	0.529	0.941	0.911	3201.32	0.000	1836

4.3.3 Analysis of Price

Both marginal and total price were found to be insignificant with regard to the TRWD dependent variable (Tables 33 and 34). Neither of the variables accounted for any of the variation in TRWD, as reflected by the low R^2 values. Within the multi-variate TRWD model, marginal price was used to represent price.

Table 33: Regression Results for Marginal Price with TRWD within the Volumetric Pricing Schedules.

TRWD = f (MP) - for all volumetric based pricing municipalities

Region	Intercept	Slope	R^2	F	F Sig	df
		MP				
Ontario	10675.528	3286.388	0.001	0.808	0.369	995
Prairies	2827.691	2119.421	0.002	2.235	0.135	914
All regions	8278.409	1194.851	0.000	0.402	0.526	1910

Table 34: Regression Results for Total Price with TRWD within the Volumetric Pricing Schedules.

TRWD = f (TP) - for all volumetric based pricing municipalities

Region	Intercept	Slope	R^2	F	F Sig	df
		TP				
Ontario	18914.72	-142.22	0.001	0.844	0.375	995
Prairies	3359.739	33.801	0.000	0.561	0.445	914
All regions	14273.339	-116.181	0.001	0.618	0.428	1910

4.3.4 Analysis of Income

Household income was insignificant with regard to TRWD. Significance values for this variable were all below the 95% level and, therefore household income accounted for none of the variations in TRWD (Table 35).

Table 35: Regression Results for Household Income with TRWD within the Volumetric Pricing Schedules.

TRWD = f (I) - for all volumetric based pricing municipalities

Region	Intercept	Slope	R^2	F	F Sig	df
		I				
Ontario	8363.23	0.03052	0.000	0.182	0.670	417
Prairies	-4051.06	0.191	0.010	2.917	0.078	403
All regions	232.28	0.141	0.009	3.102	0.053	820

4.3.5 Analysis of Rainfall

The same trends were found with regard to rainfall. Rainfall data were found to be statistically insignificant in all cases and they were considered not to account for variations in the TRWD variable (Table 36).

Table 36: Regression Results for Rainfall with TRWD within the Volumetric Pricing Schedules.

TRWD = f (SP) - for all volumetric based pricing municipalities

Region	Intercept	Slope	R^2	F	F Sig	df
		SP				
Ontario	16556.183	-9.51	0.000	0.298	0.585	995
Prairies	5792.363	-3.126	0.000	0.133	0.715	914
All regions	7404.875	-6.497	0.000	0.433	0.511	1910

4.3.6 Multiple Linear Regression Results

The multi-variate regression model for TRWD, as specified in Equation 6, was run (Table 37). Results showed that only population served by water services was significant in accounting for variations of TRWD[22]. The coefficients of determination were all above 0.9 and F values were very high.

Table 37: Regression Results for the Original TRWD Model with Municipalities Using Volumetric Schedules.

TRWD = f (Pop, P, I, SP) - for volumetric based pricing only

Region	Intercept	Slope				R^2	F	F Sig	df[1]
		Pop	MP	I	SP				
Ontario	1716.066	0.235	-404.730	0.002	-1.726	0.905	987	0.000	417
	0.296	0.000	0.646	0.915	0.642				
Prairies	994.409	0.225	-799.092	0.035	-4.872	0.944	1,663	0.000	401
	0.407	0.000	0.082	0.140	0.085				
All regions	1191.563	0.231	-823.080	0.020	-2.484	0.921	2,383	0.000	818
	0.220	0.000	0.072	0.177	0.298				

[1] Note the smaller values, as household income values are only available for 1991 and 1996.

Table 38: Regression Results for the Second TRWD Model with Municipalities Using Volumetric Schedules.

TRWD = f (Pop, MP, SP) - for volumetric based pricing only

Region	Intercept	Slope			R^2	F	F Sig	df
		Pop	MP	SP				
Ontario	1053.483	0.240	-588.032	0.979	0.970	10,910	0.000	995
	0.330	0.000	0.357	0.747				
Prairies	1862.027	0.246	-1153.467	-1.436	0.922	3,608	0.000	914
	0.013	0.000	0.004	0.553				
All regions	1366.053	0.241	-938.241	0.400	0.964	16,866	0.000	1909
	0.036	0.000	0.010	0.833				

Following the original model, the least significant variable (household income) was eliminated and the regression was run again (Table 38). Marginal prices were found to be significant within this second model for the entire dataset as well as the Prairie

[22] As noted in the beginning of this section, the population served by water services data were used here in their unlogged form. This introduces a degree of bias because of the influence of large municipalities. This bias is dealt with in the following section.

region. Population served by water services was still the most significant variable in the model.

The same process was repeated, eliminating the least significant variable from the previous model, rainfall. Again, marginal prices were found to be statistically significant within the Prairie region as well as within the entire dataset. Coefficients of determination were above 0.9 and significance levels were very high. Population served by water services was again the most significant variable (Table 39).

Table 39: Regression Results for the Third TRWD Model with Municipalities Using Volumetric Schedules.

TRWD = f (Pop, MP) - for volumetric based pricing only

Region	Intercept	Slope		R^2	F	F Sig	df
		Pop	MP				
Ontario	1343.490	0.240	-552.979	0.971	16,380	0.000	995
	0.025	0.000	0.379				
Prairies	1501.684	0.246	-1192.020	0.922	5,416	0.000	914
	0.000	0.000	0.003				
All regions	1479.011	0.241	-929.461	0.964	25,312	0.000	1909
	0.000	0.000	0.010				

Table 31 shows the regression values for population served by water services (log values). Coefficients of determination are very high and the marginal price variable does not account for a large part of the R^2 value. The final model is presented below.

4.3.7 TRWD Adjusted Model

Following the simple regressions of the TWRD model variables, only population was found to be statistically significant within the study region. Household income, and rainfall were found to be statistically insignificant variables in the two regions under study. Marginal prices were insignificant within the simple linear regression but were inconsistent within the multiple regression results. However, this independent variable accounted for a very small portion of the coefficients of determination and was therefore excluded from the final TRWD model. Also, price structure was found to be statistically significant in the entire dataset.

The R^2 values varied from 0.878 to 0.920, with F significance levels that were very low, implying that the equation is highly significant. This regression value was higher within Ontario than for the Prairie region. Analysis of the entire sample (i.e., all regions combined within volumetric-based pricing municipalities) produced a R^2 value of 0.911 for 1836 municipalities (Figure 25). Therefore, population served by water services explained a very large amount of the total variation of TRWD in municipalities. Additional figures for individual regions have been placed in Annex 4.

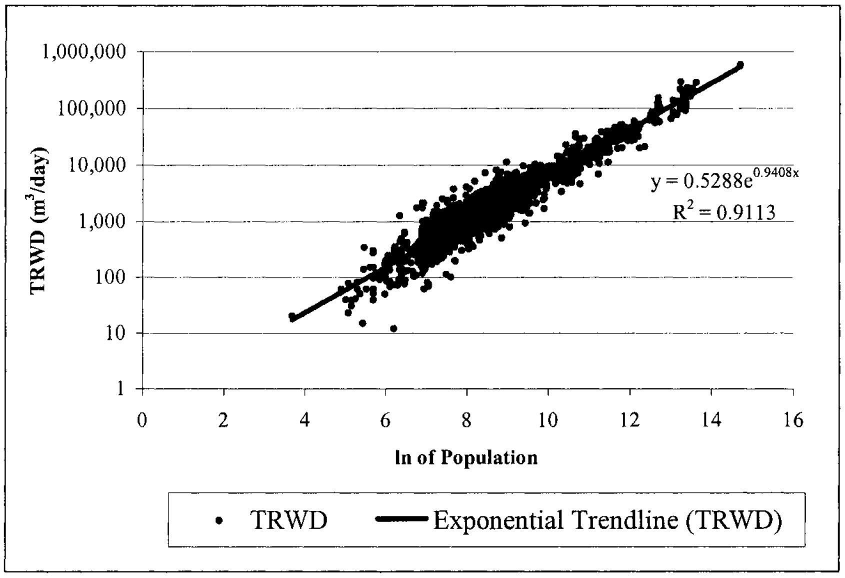


Figure 25: Total Residential Water Demand and Population Served by Water.

These results indicate that population served by water services had by far the highest influence on TRWD. With the very high regression values found in the current context of the study, population is the sole predictor of TRWD values.

The new model for TRWD therefore became:

$$TRWD = 0.5288\ e^{0.9408(\ln POP)} \quad \text{(Equation 8)}$$

4.4 RWD/capita Model

The RWD/cap model took the following form:

$$RWD/cap = a_2 + b_2P + b_3I + b_4SP + b_6D$$

After testing the independent variables mentioned above, using the methodology outlined in Chapter 3.

4.4.1 Analysis of Price Structure

Price structure, as represented by a dummy variable, was tested for each of the pooled databases. This variable was found to be statistically significant, using a t-test statistic, in explaining RWD/cap for all regions, and for all years combined. R^2 values varied from 0.048 to 0.078 (Table 40). Price structure was the variable with the highest significance in explaining variations in RWD/cap. It was, as well, the most consistent of the independent variables in accounting for variations in this dependent variable.

The results support the original hypothesis for the price structure variable, namely that municipal water pricing types do have some importance in determining the levels of RWD/cap, and that municipalities using volumetric-based pricing have lower per capita water demands than those using flat rates. It is also clear that price structure by itself accounts for quite a small percentage of total variance in RWD/cap, as reflected in the generally low R^2 values of Table 40.

Table 40: Regression Values of RWD/capita with Price Structure.

RWD/capita = f (DV) - for all municipalities

Region	Intercept	Slope DV	R_{pb}	R^2	t-test	Sig.	df
Ontario	0.4076	-0.093	-0.220	0.048	-9.230	0.000	1721
Prairies	0.4422	-0.134	-0.280	0.078	-9.900	0.000	1140
All regions	0.4166	-0.105	-0.250	0.063	-13.490	0.000	2865

4.4.2 Analysis of Price for Water Services

Price of water services was tested against RWD/cap using both the marginal price variable and the total price one (Table 41 and 42). It was found that, within the Prairie region, marginal prices were significant determinants of RWD/cap. The R^2 value for the Prairie region was 0.116, with the R^2 values for the pooled dataset being 0.030 (Table 41). In contrast, marginal prices for Ontario were found to be insignificant. On the whole, prices failed to account for a significant degree of variation in RWD/cap, with a maximum value of 0.116 (i.e., 11.6% of total variance).

Table 41: Regression Values between RWD/cap and Marginal Price for Municipalities with Volumetric Pricing Schedules.[23]

RWD/capita = f (MP) - for volumetric based pricing only

Region	Intercept	Slope MP	R^2	F	F Sig	df
Ontario	0.337	-0.0261	0.002	3.25	0.072	995
Prairies	0.399	-0.0919	0.116	121.024	0.000	916
All regions	0.369	-0.0626	0.030	59.813	0.000	1912

Table 42: Regression Values between RWD/cap and Total Price for Municipalities with Volumetric Pricing Schedules.

RWD/capita = f (TP) - for volumetric based pricing only

Region	Intercept	Slope TP	R^2	F	F Sig	df
Ontario	0.322	0.0002	0.000	0.206	0.650	995
Prairies	0.411	-0.0022	0.067	66.554	0.000	916
All regions	0.362	-0.0012	0.013	24.502	0.000	1912

Although most of the results shown throughout the thesis view the combined datasets (i.e., across time) as a whole for the two regions, the data can also be disaggregated by year. This is done in Table 44 and 45 in order to examine the price elasticity values pertaining to the data. It is stressed that this is an adjunct to the main

[23] In this, and subsequent tables of this chapter, the statistical significance is measured at over 95%. All regions highlighted in grey identify relationships that do not fall within this significance level.

analysis. Here, material already presented in section 4.3 will be recapitulated in a slightly different way to permit a complete discussion.

The discussion of TRWD demonstrated the overwhelming influence of population levels in explaining this dependent variable, as shown in the previous section, and as recapitulated in Table 43. Moreover, the constant term in the regression analyses almost always proved statistically insignificant. This allows the use of per capita flow for further analysis of the relationship between this parameter and water price.

Table 43: RWD/cap and the Correlation Between TRWD and Population.

Region	Year	TRWD = f (Pop) for flat rate			TRWD = f (Pop) for volumetric			RWD/cap Variations (%)
		Mean RWD/cap (m^3/person/yr)	R^2	Num. of Muni.	Mean RWD/cap (m^3/person/yr)	R^2	Num. of Muni.	
Ontario	1989	167.9	0.848	111	138.7	0.868	152	21%
	1991	157	0.894	181	127.8	0.923	201	23%
	1994	153.3	0.930	156	120.5	0.937	214	27%
	1996	153.3	0.928	145	113.2	0.946	215	35%
	1999	113.2	0.927	128	80.3	0.960	209	41%
	All	149.7			116.8			28%
Prairies	1989	186.2	0.866	22	116.8	0.903	87	59%
	1991	153.3	0.598	60	113.2	0.890	188	35%
	1994	153.3	0.597	50	109.5	0.924	212	40%
	1996	160.6	0.549	46	113.2	0.904	212	42%
	1999	175.2	0.622	40	113.2	0.917	211	55%
	All	164.3			113.2			45%

Intercept and slope values for RWD/cap varied greatly throughout the study regions and across time (Table 44). Additional divisions within individual databases were undertaken for comparative purposes: (a) all municipalities, (b) municipalities with volumetric-based pricing, (c) municipalities with population values under 10,000, and (d) municipalities with population levels over 10,000.

Table 44: Regression Coefficients for RWD/capita and Marginal Price (m^3/yr).

Region	Year	Mun. Size	Linear Regression Coefficient	Linear Regression Intercept	Linear Regression Sig. Level	Logarithmic Regression Coefficient	Logarithmic Regression Intercept	Logarithmic Regression Sig. Level	Number of Mun.
Ontario	1989	1	4.01	149.79	NS	-0.1341	4.85	NS	265
		2	-106.82	70.35	0.0008	-0.3416	4.49	0.0453	153
		3	29.9	167.07	NS	-0.0242	4.94	NS	165
		4	-24.25	118.08	0.0382	-0.2457	4.7	0.0408	100
	1991	1	-25.28	151.48	0.0011	-0.1982	4.92	0.0001	384
		2	-2.95	130.59	NS	-0.0496	4.79	NS	202
		3	-20.39	159.43	0.0423	-0.1683	4.98	0.0087	262
		4	-22.3	129.24	0.0326	-0.1749	4.78	0.0321	122
	1994	1	-19.47	142.95	0.0008	-0.1589	4.89	0.0001	371
		2	-6.43	129.29	NS	-0.0350	4.76	NS	214
		3	-13.97	149.69	0.0568	-0.1174	4.94	0.0177	258
		4	-16.08	119.94	NS	-0.1284	4.7	NS	113
	1996	1	-30.14	145.1	0.0000	-0.2260	4.9	0.0000	362
		2	-3.18	116.44	NS	-0.0380	4.7	NS	216
		3	-28.28	156.08	0.0001	-0.1936	4.97	0.0010	245
		4	-10.26	106.18	0.0527	-0.1101	4.63	0.0421	117
	1999	1	-23.35	108.54	0.0001	-0.2371	4.49	0.0001	339
		2	-8.11	90.26	NS	-0.1273	4.35	NS	208
		3	-35.19	110.58	0.0000	-0.4018	4.46	0.0000	202
		4	-8.13	102.17	NS	-0.1017	4.53	NS	136
Prairies	1989	1	-72.02	179.83	0.0000	-0.5294	5.08	0.0000	111
		2	-65.3	172.44	0.0000	-0.5899	5.14	0.0000	88
		3	-70.37	175.68	0.0000	-0.5411	5.04	0.0000	85
		4	-112.31	223.85	0.0029	-0.7048	5.36	0.0048	26
	1991	1	-42.21	152.33	0.0000	-0.2993	4.91	0.0000	253
		2	-40.89	150.85	0.0000	-0.3150	4.93	0.0000	190
		3	-41.76	152.78	0.0000	-0.2935	4.91	0.0000	224
		4	-36.45	140.25	NS	-0.3070	4.88	0.0470	26
	1994	1	-37.12	146.15	0.0000	-0.2826	4.9	0.0000	264
		2	-29.96	137.6	0.0000	-0.2781	4.89	0.0000	213
		3	-37.38	146.78	0.0000	-0.2861	4.9	0.0000	235
		4	-17.6	120.29	NS	-0.1817	4.78	NS	29
	1996	1	-38.48	153.15	0.0000	-0.2655	4.91	0.0000	260
		2	-32.54	145.63	0.0000	-0.2643	4.91	0.0000	213
		3	-38.53	154.5	0.0000	-0.2673	4.92	0.0000	231
		4	6.47	89.52	NS	0.0644	4.45	NS	29
	1999	1	-29.67	149.62	0.0000	-0.2021	4.89	0.0000	251
		2	-25.14	143.64	0.0004	-0.1993	4.89	0.0003	210
		3	-29.59	152.12	0.0001	-0.1963	4.91	0.0001	217
		4	-24.68	128.2	0.0256	-0.2012	4.78	0.0342	34

NOTE: 1 = All Municipalities

2 = Only Municipalities with volumetric rates

3 = Municipalities with population lower than 10,000

4 = Municipalities with population higher than 10,000

NS = Not significant

The Ontario regression coefficients, within linear regression, generally showed no consistency over time, and were statistically insignificant except for 1989. Municipalities over and under population values of 10,000 were more consistent, because they were found to be significant on greater occasions. Slope coefficients, however, varied between –10.26 to -106.82 m^3/yr/person. These coefficients indicate that an increase in marginal price by $1 will decrease RWD/cap values to the coefficient levels mentioned above.

Conversely, the Prairie region was more statistically significant within the different subsets. Values for linear regression slope coefficients varied from –24.68 to –112.31, generally decreasing through time. Municipalities over 10,000 persons were generally insignificant, most likely due to the smaller sample sizes within this category.

As outlined previously, price elasticity is a measurement value of the impact of varying prices on demand, and is defined as the percentage change in quantity demanded divided by the percentage change in price. In water demand terms, it measures the influence of varying prices of water demand by taking the ratio of the percentage change in quantity of water demanded to the percentage change in price. Elasticity is generally classified into two broad categories: inelastic demand and elastic demand. Demand is deemed inelastic whenever the elasticity coefficient varies between zero and one. When it is greater than one, economists say that the demand is elastic. Goods that have few substitutes usually have lower elasticity values of demand than others with many substitutes. This value is measured by the slope coefficients in a logarithmic regression equation.

Research on municipal water demand has shown that price elasticity values vary greatly in different contexts (Annex 1). Within the study period, these values fluctuated between -0.16 and -0.59 (Table 45). Elasticity values within Ontario were generally more constant and lower than those of the Prairie region. The latter showed decreasing elasticity values through time. These went from –0.53 to –0.20 (1989 to 1999) within the entire dataset, while municipalities with volumetric-based rates had elasticity values decreasing from –0.59 to –0.20.

Table 45: Price Elasticity Values for Region of Study, 1989-1999.

Region	Year	Elasticity	
		All	Volumetric
Ontario	1989	-0.13	-0.34
	1991	-0.20	-0.05
	1994	-0.16	-0.03
	1996	-0.23	-0.04
	1999	-0.24	-0.13
Prairies	1989	-0.53	-0.59
	1991	-0.30	-0.31
	1994	-0.28	-0.28
	1996	-0.27	-0.26
	1999	-0.20	-0.20

4.4.3 Analysis of Density

Density was tested with RWD/cap and was found to be statistically insignificant in the two different regions (Table 46). Overall this independent variable was weak in accounting for total variance in RWD/cap. Datasets comprised of all municipalities showed weak results.

Table 46: Regression Values between RWD/cap and Density for Municipalities with Volumetric Pricing Schedules.

RWD/capita = f (D) - for volumetric based pricing only

Region	Intercept	Slope	R^2	F	F Sig	df
		D				
Ontario	0.315	-5.59E-08	0.000	0.005	0.941	995
Prairies	0.321	-0.0000277	0.004	3.590	0.058	916
All regions	0.312	-6.61E-08	0.000	0.010	0.920	1912

4.4.4 Analysis of Income

Household income was insignificant in accounting for variations in RWD/cap (Table 47). Within both regions, the regression results were insignificant. They remained insignificant within the entire dataset.

Table 47: Regression Values between RWD/cap and Household Income for Municipalities with Volumetric Pricing Schedules.

RWD/cap = f (I) - for all volumetric based pricing municipalities						
Region	Intercept	Slope	R^2	F	F Sig	df
		H				
Ontario	0.376	-0.000000817	0.005	2899.000	0.089	417
Prairies	0.32	-0.000000206	0.000	0.076	0.783	403
All regions	0.332	-0.000000228	0.000	0.387	0.534	820

4.4.5 Analysis of Rainfall

Rainfall was defined as summer precipitation values (for months of June, July, August and September). These two terms will be used interchangeably within this section. Regression values varied from 0.002 to 0.03 within the significant databases in the study (Table 48). The Prairies were significant, with only the 1991 database not responding to summer precipitation. Similar results were found within the Prairies datasets, since 1991 was statistically insignificant as well as 1999.

However, the slope coefficients within this variable behaved differently from what was hypothesised. Although the Prairie slope coefficients was negative in nature (which was expected), the Ontario one was positive. It is noteworthy to add that both regions have very small slope coefficients that make the curve almost flat.

Table 48: Regression Values between RWD/cap and Rainfall for Municipalities with Volumetric Pricing Schedules.

RWD/capita = f (R) - for volumetric based pricing only

Year	Intercept	Slope	R^2	F	F Sig	df
		SP				
Ontario	0.397	0.00005287	0.001	0.587	0.444	995
Prairies	0.387	-0.000283	0.030	28.703	0.000	916
All regions	0.338	-0.0000857	0.002	3.973	0.046	1912

4.4.5 Multiple Linear Regression Results

Price structure was shown to be statistically significant for the entire dataset. Marginal price was found to be significant within municipalities using volumetric-based pricing schedules for the Prairie region, but not within Ontario. Rainfall was found to be significant in some regions. Household income and density were found to be insignificant variables for RWD/cap in any of the given years, in either region.

The original model was completed (Table 49) and was found to be significant within the Prairies but not within Ontario. Household income was the weakest variable. Density was insignificant in the entire dataset and within the individual regions. Rainfall and marginal prices were significant in both the entire dataset and the Prairie region but not in Ontario.

Table 49: Regression Results for the Original RWD/cap Model Using Municipalities with Volumetric Pricing Schedules.

RWD/capita = f (MP, SP, D, I) - for volumetric based pricing only

Year	Intercept	Slope				R^2	F	F Sig	df
		MP	SP	D	I				
Ontario	0.416	-1.080	-0.00025	-0.00003	0.00000	0.003	2.719	0.011	417
	0.000	0.140	0.084	0.120	0.962				
Prairies	0.460	-0.091	-0.00027	-0.00005	0.00000	0.130	15.989	0.000	403
	0.000	0.000	0.001	0.075	0.487				
	0.425	-0.064	-0.00001	-0.00002	0.00000	0.055	12.865	0.000	820
All regions	0.000	0.000	0.042	0.100	0.979				

A second model was run, eliminating the least significant variable, household income (Table 50). Density was found to be insignificant in the entire dataset as well as within Ontario. It was the weakest variable of this second model. The Ontario model as a whole was insignificant, while the Prairie model was very significant.

Table 50: Regression Results for the Second RWD/cap Model Using Municipalities with Volumetric Pricing Schedules.

RWD/capita = f (MP, SP, D) - for volumetric based pricing only

Year	Intercept	Slope			R^2	F	F Sig	df
		MP	SP	D				
Ontario	0.314	-0.0288	7.61E-05	-6.60E-08	0.001	1.48	0.218	991
	0.000	0.050	0.277	0.930				
Prairies	0.469	-0.089	-0.0002	-4.10E-05	0.137	49.49	0.000	916
	0.000	0.000	0.000	0.030				
All regions	0.383	-0.0615	-4.80E-05	-1.60E-07	0.03	20.379	0.000	1912
	0.000	0.000	0.258	0.810				

4.4.7 RWD/cap Adjusted Model

The final multiple linear regression model was built using two independent variables: marginal price and rainfall (Table 51). Regression values varied from 0.002 to 0.130. They were higher within the Prairie region. The model was statistically significant within the Prairies while the Ontario model was not.

As for individual independent variables, marginal price was statistically significant within the Prairies and was found to be statistically significant within Ontario. Summer precipitation was a weaker variable, being statistically significant within the Prairies but not in the entire dataset. Slope coefficients were, nevertheless, as hypothesised, that is negative.

R^2 values were very low; the independent variables clearly did not account for a large proportion of total variance in RWD/cap. Accordingly, there was a large degree of randomness in the datasets. The possible causes of this randomness are discussed in sections of Chapter 5.

Table 51: Regression Values between RWD/cap and Independent Variables for Municipalities with Volumetric Pricing Schedules.[24]

RWD/capita = f (MP, SP) - for volumetric based pricing only

Region	Intercept	Slope		R^2	F	F Sig	df
		MP	SP				
Ontario	0.314 0.000	-0.0288 0.050	7.61E-05 0.276	0.002	2.219	0.109	995
Prairies	0.449 0.000	-0.0866 0.000	-0.0002 0.000	0.130	69.137	0.000	916
All regions	0.383 0.000	-0.0615 0.000	-4.8E-05 0.257	0.030	30.554	0.000	1911

[24] As for previous tables, top values within the different rows outline the coefficients, while bottom ones give the statistical significance of the variable, these are measured by the t-test. Again, regions in grey denote statistical insignificance.

CHAPTER V

A Discussion of Results

This chapter discusses the results outlined within Chapter 4. It begins by examining the implications of the results of both the TRWD model and the RWD/cap model. It is then followed by discussing the possible implications of variations within the geographical regions under study. It concludes by the presentation of three different themes that were crucial results of the current research: the important role of pricing schedules, the price-responsiveness of water demand, and the low values for the coefficients of determination.

5.1 TRWD Model Implications

The TRWD model, outlined in Chapter 4, showed that population served by water services was the only significant variable, in the individual regression analyses in accounting for variations in TRWD. Coefficients of determination were approximately of 0.9 in each dataset and in the combined regions.

These results have implications in the water demand forecasting field. A simplistic form of water demand forecasting multiplies per capita water demand coefficients by projected population levels to produce water demand forecasts. Although this method has been criticized in the past for being too simplistic, this research shows that, in fact, it might be appropriate for forecasting at the inter-municipal level (i.e., the regional level of study).

The major criticism of so-called "coefficients method of forecasting" has been that the variations in water demands were all accounted for by the population variable, offering few choices for developing policies to alter demand levels. The cost of adding an extra individual would become the only factor that would be influencing water demand levels, and therefore no economic factors could play a role in influencing demand levels.

To some extent, this criticism may or may not be accurate depending upon the geographical scale of the study being undertaken, or the particular task at hand. This study suggests that population levels were important in explaining inter-municipal water demands. It therefore implies that at a regional level of planning one could use the simplistic model to carry out predictions in future water demand levels. For example, in predicting future residential water demand levels within Ontario, one could multiply predicted population levels for the time frame of interest with an average per capita residential water demand level.

However, these results say nothing about the explanation of intra-municipal demands. In planning for infrastructure in individual municipalities more detailed analyses of the determinants of demand would have to be carried out. For example, variables considered in the latter might be: number of persons per household, lot size, household income, etc., which have been shown in previous studies to have some explanatory importance. The results of this research should not be taken as a justification for applying simplistic methodologies to projecting water demands for individual communities.

5.2 RWD/cap Model Implications

The RWD/cap model was built using the volumetric-based pricing databases only, employing two independent variables: marginal price and rainfall. Price structure was shown to be statistically significant within the entire dataset. Marginal price was found to be significant within municipalities using volumetric-based pricing schedules for the Prairie region, but not within Ontario. Density was found to be significant on some occasions, and was therefore eliminated due to its great inconsistencies. Rainfall was a more stable variable although it showed similar patterns to density and was included in the final model. Household income was found to be an insignificant variable for RWD/cap in any of the given regions.

There are significant implications in the testing of these independent variables, especially those linked to pricing structure and price of water services. Although some of these basic implications are discussed within this section, later sections within this chapter, address these issues in greater detail.

In some sense, the independent variables - density, household income, and rainfall- are all related indirectly to price of water services. In other words, the hypotheses about the impacts of these three variables reflect the importance of economic factors within residential water demand, especially those related to water prices. Density, for example, may be viewed as being linked to outdoor water demands in that larger lot sizes (i.e., reflecting higher incomes) will lead to higher outlays for water, and might event push the consumer into blocks of water usage having higher marginal prices. Household income might act in the same way, with the added effect of increasing indoor (e.g., additional household appliances) water demands. Rainfall levels (an variable not controllable by householders) will lower outdoor water demands in wetter years, and may substantially reduce outlays on water due to higher price elasticities for outdoor uses. It is, consequently, not surprising that most of these variables were weak or insignificant in accounting for variations in per capita demand, when marginal prices were almost insignificant themselves. None of this discussion is meant to imply that density, income, or rainfall are functions of water price, for that is clearly not so. The discussion suggests only that subtle relationships among the variables may be causing high randomness (and therefore low levels of explanation) in the RWD/cap model.

Household income results are perhaps the most surprising. It was by far the most insignificant variable within both dependent variables but more importantly within RWD/cap. Justifications for these results can possibly be found within the context of the present research. Within this inter-municipal study, average values of household income were taken for each individual municipality. As a result, high and low income earners were possibly balanced out and, although variations within the databases were seen, perhaps the averages smoothed out these variations. Kitchen (1975) obtained similar results for household income at the inter-municipal level within 31 Canadian municipalities. It was also found that household income was insignificant in regard to residential water demand.

It is well established that certain large urban centres, for example, have higher income suburbs as well as low income ones. Conceivably it could be the scale at which this variable is looked upon that was incorrect. Headley (1963) analysed at a smaller geographical scale, that of a region, not a province or state level. Within the literature, it is well confirmed that household income plays a role in determining variations within per capita demands at an intra-municipal level. Although research has shown similar results at the inter-municipal level within regions, a further extrapolation to larger units might be impossible.

Density values had similar significance problems as those found in household income. Density has been outlined, within the inter-municipal water demand literature, as an important determinant in describing variations within per capita demands, and has been viewed as within the municipal structure characteristics variable category. Density values are generally stable through time and vary only slightly for an individual municipality.

Density was found to be a weak indication of municipal structures and did not account for any of the variation in RWD/cap within this study. It is, perhaps, the choice of this variable to represent municipal characteristics that was weak. It was, however, the only data that was available within the context of this study.

Rainfall results were semi-consistent with most of the regions in exhibiting statistical significance, particularly in the Prairies. These results are of importance because they indicate that climatic variations between years played an important role in determining variations in RWD/cap values in the Prairies and not in Ontario. One of the purposes of examining the rainfall variable was to determine whether drier or more humid years had an impact on RWD/cap values. It was determined that within the Prairies, climatic variations do, indeed, account for a significant part of the variations of RWD/cap. These variations are, however, very weak as coefficients of determination were fairly low. The Ontario coefficient had a positive value, which was unexpected. The explanation for such a result is not difficult. In municipalities with low summer precipitations, the frequency of imposing controls (when they exist) or the frequency of warnings (through the media) with regard to the serious consequences of excessive demand for water (e.g., for sprinkling use), appear to be higher and the controls or warnings tend to be effective. While it is virtually impossible to verify statistically such a conclusion, many water policy-makers have stated that warnings and controls have a noticeable impact on the quantities demanded (Kitchen, 1975).

Price structure was the variable with the most consistency in explaining variations in RWD/cap of all the independent variables. The implications of these results are addressed within section 5.4. The results, however, do support the original hypothesis for the price structure variable, namely that municipal water pricing types do determine the variation in levels of RWD/cap. Municipalities using volumetric-based pricing also have lower per capita water demands than those using flat rates. Price implications are discussed in section 5.5.

5.3 Geographic Variations

One of the most important research finding of the thesis was that the two regions at study had significant differences between themselves and did not exhibit similar water demand patterns. Within rate schedules, they had varying characteristics, because most of the Prairie region had volumetric pricing, whereas only 50% of Ontario municipalities had those types of rate schedules in place.

With respect to price variations, total and marginal prices values were higher within the Prairies than in Ontario. Marginal prices were found to be statistically significant in explaining variations of RWD/cap values in the Prairies. Generally, due to this fact, the coefficient of determination within the Prairies was higher than for Ontario.

Within the cross-sectional analysis, it was found that rainfall was statistically insignificant for the combined dataset. This variable did not determine variations in RWD/cap, possibly due to the significant climatic differences between the two regions.

5.4 Price Structure Importance

Price structure was a significant predictor of RWD/cap levels. It was found to be statistically significant for all regions combined and within the entire dataset. The shift from flat rates to volumetric rates is the first step to controlling water demand levels. Within flat rates, the municipality has no way of knowing how much water is being used by various customers because there are no meters to measure demand. Also, there access to reliable data on water loss in the system (a measure of the quality of the water-servicing infrastructure) is made more difficult. This may be a serious problem in that leakage can cost the municipality thousands of dollars annually. With the establishment of volumetric-based pricing, consumers play a special role in leak detection programs, because they verify the quantity of water they are charged for and report possible errors (i.e. leaks in the system).

The first step to managing a resource is understanding patterns and trends of use. Information on water needs is necessary to ensure that the water requirements are met currently and that appropriate measures can be put into place to guarantee that future demands can also be met. Individuals within municipalities using flat rates have no conservation incentives for residential water demand, as water servicing is a classic free good. Since consumers pay a flat charge for the water demanded, they have no incentive to restrict their water usage.

Although the addition of metering infrastructure may seem costly, its total costs are small in relations to total water system costs (Tate and Lacelle, 1995) and "payback periods" are short. Also, benefit-cost analysis has demonstrated that, in all cases, the decision to meter water supplies produces benefits in excess of costs. The metering decision has two dimensions, equity and efficiency. The equity argument for metering is clear; it permits volumetric charges, which means payment according to the quantity of water used (and approximately the quantity of waste disposed into the sewers). The efficiency argument can be approached by considering metering like any investment making decision, as characterized by the excess of benefits to costs. Hanke (1981) used a "shortcut" procedure for the benefit cost decision on the extension of metering in Perth, Australia. He found that total benefits during the period of study were just over $783,000 while costs were just over $241,000. Thus the excess of benefits over costs was about $542,000. This finding exemplifies many other studies that have been conducted on metering around the world.

The transition from flat rate pricing to volumetric pricing introduces the user-pay principle. The user-pay principle is a straightforward one, which states that individual users should, as far as possible, be responsible for the costs that their water servicing demands impose on the public water utility.

The principle of user pay could be extended to the full-cost pricing principle to improve the efficiency and financial sustainability of water systems. Paying the full costs of water services helps to assure that prices associated with supplying water services are reflected in all consumption decisions. Unless the full social costs of water services are reflected in rates, consumers will not have a rational economic signal to guide their decision-making. Until rates recover the costs of water services, suppliers will have to rely on outside funding sources and/or provide low quality service.

In many municipalities within the study region, a large portion of the costs of water services are externalized to provincial taxpayers through capital facility grants (Sancton *et al.*, 2001). As a consequence, water prices do not reflect the value of the resources demanded in providing this service. Therefore, municipalities do not raise the capital funds necessary to maintain and develop added infrastructure and demand capital grants as mentioned above. This becomes a circular problem. The National Round Table on the Economy and the Environment (1996) stated:

> "The challenges could be addressed by moving toward full cost, user pay, direct customer charges for water and wastewater services. Such a pricing system would help attract the capital needed to maintain and augment Canada's water infrastructure. Moreover, by paying directly for water service, consumers would create the revenue flow to retire the debt incurred in retrofitting existing infrastructure and building new infrastructure. New environmental and economic opportunities would follow."

Municipalities with older water supply systems in need of extensive repairs or replacement face the most difficult problems. With all levels of government moving towards the adoption of policies for realistic water pricing and user pay principles, many municipalities are moving towards the principles outlined above and have instituted full-cost pricing to recover the total cost of providing both water and sewer services including the costs of financing the replacement of older systems and the upgrading of overloaded treatment plants. Higher municipal costs, in turn, are transferred to the consumers, which mean higher water and sewer bills for water services.

5.5 Water Demand and Price

The present research confirms that residential water demand is responsive to water prices. Marginal prices were found to be statistically significant within the Prairie region and for the combined year databases in explaining variations in per capita dependent variable.

Price elasticity values were found to be consistent to the ones outlined within the residential water demand literature. Elasticity values within Ontario were almost constant insignificant part in the total household budget. This brings no additional incentives for water conservation initiatives.

In addition, these low coefficients could possibly be due to a problem of scale. The choice of regions (including a large province as well as three provinces combined) could play an important part in the low coefficients found. Although previous studies at a provincial level had provided higher R^2 values for a series of similar variables (Harris, 1994), perhaps Ontario and the Prairies have great differences within the datasets that strongly affect the coefficient values.

at the –0.2 value. The latter showed decreasing elasticity values through time. These values went from –0.53 to –0.20 (within the entire dataset), and from –0.59 to –0.20 (in municipalities with volumetric-based rates). Average price elasticity values were, for Ontario, –0.2, and –0.3 for the Prairies.

Residential water demand in Ontario was, therefore, more inelastic than in the Prairies. These values established that there exist fewer substitutes to water in Ontario than within the Prairie Provinces. The Prairie region has developed more alternatives (or simply consumers have chosen to reduce demand levels) for residential water demands. With lower prices in Ontario, consumers have had no need to seek out new alternatives, as they feel satisfaction from current price/quantity ratios.

5.6 Low Coefficients of Determination

Within the thesis, coefficients of determination values varied from 0.030 to 0.130. These values were in general higher within the Prairie Provinces. The model was statistically significant within the Prairies while the Ontario model was not.

These low coefficients of determination were fairly unexpected, because past research had shown that pricing variables produced higher coefficients of determination. The low coefficients within the regions of study are caused by a high degree of randomness within the datasets.

Water prices within the region were particularly low and therefore, as outlined within Figure 8 (page 27), they fit in the lower end of the curve. The effects of price increases (i.e., the higher prices within the region of study) are found to have negligible impacts on variations of residential water demand levels. Water servicing costs are an

CHAPTER VI

Conclusions, Implications and Future Research Directions

The research reported in the thesis supports a number of conclusions. The implications of these results within the water management field are also presented. As well, a direction of future possible research is also offered in the concluding section of this chapter.

6.1 Conclusions and Implications

The research centered on the factors that explain variations within residential water demand in two different regions of Canada. To accomplish this task, the regression analysis statistical technique was used on water demand data compiled by Environment Canada, for five different years, within two Canadian regions: Ontario and the Prairie Provinces. Two dependent variables were used: total residential water demand and residential water demand per capita.

Within the TRWD model, population served by water services was found to be the only statistically significant variable, with coefficients of determination around 0.9. These results have implications in the water demand forecasting field. It was therefore found, that for forecasting of regional water demands, multiplying a predicted population level with a per capita coefficient might be a sufficient technique. Other variables tested included price structure, price of water services, household income and rainfall.

With respect to the RWD/cap model, marginal prices were found to be statistically significant within the Prairie region but not within Ontario. Price elasticity values averaged –0.2 for Ontario and –0.3 for the Prairies. These values are consistent with other elasticity values found in concurrent work in different regions. The rainfall variable was also found to be statistically significant, with certain exceptions. These two variables were therefore added to the multiple linear regression model. Price structure was also tested on the entire dataset and was the variable that had the highest coefficients of determination and was consistently significant throughout the entire datasets and regions. The shift from flat rates to volumetric rates is the first step to controlling water demand levels. The coefficients show this trend. Other variables tested included density, and household income but these were not found to be statistically significant.

The multiple regression model produced R^2 values that were quite low. The independent variables clearly did not account for a large proportion of total variance in RWD/cap. Accordingly, there was a large degree of randomness in the datasets. These low coefficients of determination were fairly unexpected, as past research within different regional contexts had shown that the selected independent variables produced higher coefficients of determination. One of the possible reasons for obtaining such low coefficients was the low water prices within the region of study. Since these prices were so low, consumers did not react to changes as the water bills account for such a small portion of the water budgets. Also, the regions outlined might be to vast.

6.2 Future Research Directions

This inter-municipal study of factors underlying residential water demand brought about a different approach to traditional intra-municipal studies. Although not many of the original five independent variables were found to be statistically significant in accounting for variations of residential water demand, an intra-municipal study, in conjunction to the one carried out here, using controlled and consistent samples, would be advantageous in comparing the two types of approach. A selected sample of municipalities could have been chosen and analysed in conjunction with ~~to~~ the inter-municipal study just completed. This would provide additional insight and would serve as well as a contrast to the importance of select variables on another scale. A series of planning implications could therefore be derived from such a study.

Also, price structure was found to be the most statistically significant determinant of per capita residential water demand variations. Metering was consequently viewed as an important infrastructure development in possibly controlling residential water demand levels. Additional insight on the implications of pricing structure would greatly enhance the state of knowledge of Canadian components of residential water demands.

Concurrently, the integration of full-cost pricing principles into the financing of municipal water infrastructure would be beneficial in areas where public funding is constrained. This idea has been discussed frequently in theory, but has experienced considerable reluctance to being employed practically. Further research, both of the type carried out here, and projects aimed at integrating demand management into actual financial decisions about water infrastructure financing would save large amounts of money in the future.

Although this study focuses on the residential component of municipal water demands, additional work could be developed on the issues of commercial water demands and industrial water demands, that is those that are serviced within the municipalities' water supply services. The broadening from the current, and most popular, section of municipal water demand could greatly aid in further understandings of issues and problems that municipal water planners face. In developing additional insight as to the complete factors that explain variations of water demands, one becomes more knowledgeable.

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Annex 1: Price and Income Elasticities in North America

Price and Income Elasticities in North America							
Year	Author	Study Location	Type of Use	Type of Data	Type of Model	Price Elasticity	Income Elasticity
1951	Larson and Hudson	15 communities in Illinois	M & I	CS			0.7
1957	Seidel and Baumann	111 areas in the U.S.	M & I	CS	L	-0.12 to –1.00	
1958	Fourt	34 U.S. cities	M & I	CS	LL	-0.39	0.28
1963	Bain	Northern California	M & I	CS	LL	-1.1	0.58
1963	Gottlieb	Kansas	M & I	CS	LL	-0.67 to –1.23	0.28
1963	Headley	San Fransisco Bay Area	M & I	TS	L		0.4
1964	Gardner-Schiek	Northern Utah	M & I	CS	LL	-0.77	
		Northern Utah	M & I	CS	L	-0.67	
1965	Flack		M & I	CS	1	-0.12 to –0.61	
1966	Ware and North	Georgia households	SF Residential	CS	LL	-0.61	0.38
		Georgia households	SF Residential	CS	L	-0.67	0.83
1967	Conley	So. California	Agg. Residential	CS		-1.02	
1967	Howe and Linaweaver	21 areas across the U.S.	SF Residential, annual	CS	L	-0.4	0.47
		21 areas across the U.S.	SF Residential, winter	CS	L	-0.23	0.32
		11 areas in the east 11 areas in the west	SF Residential, summer	CS	L	-1.57	1.45
		10 areas in the east 10 areas in the west	SF Residential, summer	CS	L	-0.73	0.69
1969	Turnovsky	19 Massachusetts towns	Agg. Residential	CS	L	-0.25, -0.28	
1970	Male, Willis, Babin, and Shilito	Northeast US	Agg. Residential	CS	L	-0.2	
		Northeast US	Agg. Residential	CS	LL	-0.37	
1970	Hittman Assoc.	United States	Agg. Residential	CS	LL	-0.44	
1971	Young	Tucson, Arizona	M & I	TS	L	-0.65	
		Tucson, Arizona	M & I	TS	LL	-0.69	
1972	Wong	City of Chicago, 1951-61	M & I	TS	LL	-0.02	0.2
		Chicago suburbs, 1951-61	M & I	TS	LL	-0.28	0.26

Price and Income Elasticities in North America							
		Chicago suburbs, Over 25,000, 1961	M & I	CS	LL	-0.53	1.03
		Chicago suburbs, 10-25,000, 1961	M & I	CS	LL	-0.82	0.84
		Chicago suburbs, 5-10,000, 1961	M & I	CS	LL	-0.46	0.48
		Chicago suburbs, Under 5,000, 1961	M & I	CS	LL	-0.27	0.58
1972	Grima	Toronto, Ontario	SF Residential, Annual use	CS	LL	-0.93	0.56
		Toronto, Ontario	SF Residential, Winter use	CS	LL	-0.75	0.41
		Toronto, Ontario	SF Residential, Summer use	CS	LL	-1.07	0.51
1973	Morgan	92 residences in Santa Barbara County	SF Residential, Winter use	CS+TS, monthly	L	-0.49	0.53
		92 residences in Santa Barbara County	SF Residential, Winter use	CS+TS, monthly	LL		0.43
1974	Primeaux and Hollman	402 households in 14 Mississippi cities	SF Residential	CS	LL	-0.45	0.24
		402 households in 14 Mississippi cities	SF Residential	CS	L	-0.37	0.26
1974	Sewell and Roueche	17 areas in Victoria, B.C., 1954-1970	M & I	CS+TS	L	-0.46	0.27
		17 areas in Victoria, B.C., 1954-1970	M & I	CS+TS	LL	-0.39	0.19
1975	Andrews and Gibbs	Miami, Florida	M & I	CS	SL	-0.62	0.8
1975	Hogarty and Mackay		SF Residential, short-run	CS+TS	L	-0.86	
			SF Residential, long-run	CS+TS	L	-0.56	
1975	Pope, Steppl, Lytle	South Carolina households, 1965-71	SF Residential, irrigators	CS+TS	L	-0.31 to –0.67	
		South Carolina households, 1965-71	SF Residential, Non-irrigators	CS+TS	L	-0.06 to –0.36	
1976	Grunewald, Haan, Debertin, and Carey	Kentucky	Agg. Residential	CS	LL	-0.92	
1976	Morgan and Smolen	33 areas in Southern California	M & I, annual	CS	L	-0.44	0.33
		33 areas in Southern California	M & I, winter	CS	L	-0.45	

Price and Income Elasticities in North America							
		33 areas in Southern California	M & I, summer	CS	L	-0.43	
1977	Clark and Goddard	22 areas	M & I	CS	L	-0.63	
		22 areas	M & I	CS	LL	-0.6	
1977	Gallagher and Robinson		SF Residential, winter	CS+TS	LL	-0.24	
1977	Gardner	Minnesota areas	Agg Residential	CS	L	-0.24	
		Minnesota areas	Agg Residential	CS	LL	-0.15	
1977	Danielson	Raleigh, North Carolina	M & I, annual	TS		-0.27	
		Raleigh, North Carolina	M & I, winter	TS		-0.305	
		Raleigh, North Carolina	M & I, summer	TS		-1.38	
1978	Camp	288 households in 10 Mississippi cities	SF Residential	CS	L	-0.24	
1978	Carver	Fairfax, Co, 1974-75	Agg Residential, Summer	TS, monthly	L	-0.13 to –0.17	
		Fairfax, Co, 1974-75	Agg Residential, winter	TS, monthly	L	-0.02 to –0.04	
1978	Gibbs	Households in Miami, Florida	SF Residential	CS+TS	L	-0.51 to –0.61	0.51 to 0.8
1979	Cassuto and Ryan	Oakland, 1970-75	Agg Residential	TS+CS	L	-0.14 to –0.3	
1979	Danielson	261 households in Raleigh, NC, 1969-74	SF Residential, annual	CS+TS	LL	-0.27	0.33
		261 households in Raleigh, NC, 1969-74	SF Residential, winter	CS+TS	LL	-0.3	0.35
		261 households in Raleigh, NC, 1969-74	SF Residential, summer	CS+TS	LL	-1.38	0.18
1979	Foster and Beattie	217 U.S. cities	M & I	CS	SL	-0.53	0.18
		New England	M & I	CS	SL	-0.43	
		Midwest	M & I	CS	SL	-0.3	
		South	M & I	CS	SL	-0.38	
		Plains	M & I	CS	SL	-0.58	
		Southwest	M & I	CS	SL	-0.36	
		Pacific Northwest	M & I	CS	SL	-0.69	
1979	Male *et al.*	Eastern United States	M & I	CS	L	-0.2	0.25
		Eastern United States	M & I	CS	LL	-0.68	0.46
		Eastern United States	M & I	CS	SL	-0.35	0.55
1980	Agthe and Billings	Tucson, Arizona 1974-77	Agg Residential	TS	L	-0.18, -0.36	
		Tucson, Arizona 1974-77	Agg Residential	TS	LL	-0.18, -0.26	

Price and Income Elasticities in North America							
1980	Ben-Zvi	Red River Basin	Agg Residential, Annual	CS	LL	-0.73	
		Red River Basin	Agg Residential, Winter	CS	LL	-0.79	
		Red River Basin	Agg Residential, Summer	CS	LL	-0.82	
1980	Billings and Agthe	Tucson, Arizona 1974-77	Agg Residential	TS	LL	-0.27	
		Tucson, Arizona 1974-77	Agg Residential	TS	L	-0.49	
1980	Carver and Bolland	13 areas	M & I, winter, long-run	TS+CS	L	-0.7	
		13 areas	M & I, winter, short-run	TS+CS	L	-0.5	
		13 areas	M & I, summer, long-run	TS+CS	L	-0.11	
		13 areas	M & I, summer, Short-run	TS+CS	L	-0.1	
1980	Morris and Jones	Households	SF Residential, Annual	CS	LL	-0.39	
		Households	SF Residential, Winter	CS	LL	-0.09	
		Households	SF Residential, Summer	CS	LL	-0.73	
1981	Foster and Beattie	United States	M & I	CS	SL	-0.47	0.46
1981	Hansen and Narayanan	Salt Lake City, 1961-77	M & I	TS	LL	-0.47	
1982	Billings	Tucson, Arizona 1974-77	M & I	TS	L	-0.66	
		Tucson, Arizona 1974-77	M & I	TS	LL	-0.56	2.14
1982	Howe	United States	SF Residential	CS		-0.06	
		United States, east	SF Residential, Summer	CS		-0.57	
		United States, west	SF Residential, Summer	CS		-0.43	
1982	Morgan	473 households in Oxnard, California	SF Residential	CS+TS monthly	L		0.46
1984	Jones and Morris	326 households	SF Residential	CS	LL	-0.21	
1987	Moncur	1281 households in	SF	CS+TS	L		0.38 to

Price and Income Elasticities in North America							
		Honolulu	Residential	monthly			0.8
1989	Billings and Day	11 districts in Tucson, Arizona, 1974-1980	Agg Residential	CS+TS			0.36
1989	Weber	12 sub-districts of EBMUD, Oakland	Agg Residential, winter	TS+CS	L	-0.2	
		12 sub-districts of EBMUD, Oakland	Agg Residential, winter	TS	L	-0.08	
1990	Boland, McPhail, and Opitz	Households in Southern California	SF Residential, Winter	CS+TS	LL	-0.01 to –0.02	
		Households in Southern California	SF Residential, Summer	CS+TS	LL	-0.13 to –0.18	
1991	Dziegielew-ski and Opitz	Metropolitan Water District of Southern California	SF Residential, Summer	TS+CS	LL	-0.24	
		Metropolitan Water District of Southern California	SF Residential, Winter	TS+CS	LL	-0.39	
		Metropolitan Water District of Southern California	MF Residential, Summer	TS+CS	LL	-0.13	
		Metropolitan Water District of Southern California	MF Residential, Winter	TS+CS	LL	-0.15	

SOURCE: Baumann *et al.* 1998

KEY: SF = single family; MF= multifamily; Agg = aggregate; CS = cross-section; TS = time series; L = linear demand; LL = log-log demand; SL = semilog demand.

Annex 2: MUD Database Description

The MUD database is designed to provide easy access to basic data on municipal water and wastewater. This database (spreadsheet) currently contains water and sewage systems information from 1359 Canadian municipalities with populations over 1000. The total population of these municipalities is 24.7 million out of a total 1996 Statistics Canada Census population of 28.8 million. The database is now "up-and-running", debugging and other tests having been completed. The data are usually released in a LOTUS 123 (version 3) spreadsheet format, and can be sorted into a variety of aggregations, including; provincial, regional, hydrologic, population size groups, and others. For additional information, contact Valerie Sexton at valerie.sexton@ec.gc.ca

1. General Information

All of the data have been entered on a "municipality specific" basis, rather than on a "plant specific" basis. In other words, the database quantifies the water actually used in each municipality, rather than the more general water or sewage plant information. Some revision or estimation procedures were used when municipalities utilised shared systems. A primary advantage of this type of information is that all municipalities will have independent data, and possible double counts (within shared systems) will have been removed.

The information presented in this database (MUD) is rather general, and is primarily aimed at the production of aggregate and summary statistics. The basic types of data collected can be summarised as follows: Municipal Population (six base years), Populations Served (water and sewer systems), Average Daily Flows (water and treated sewage), Water User Classes (four different classes), Water Source (ground, combined, or surface), Sewage Treatment Type (primary, secondary, etc.), and a field summarising quantity or quality problems by year. A few specific questions relating to such issues as water disinfection/treatment types, maximum water flow, BOD5 discharge values, and final effluent disinfection/discharge, were added in 1996. There is also a small section with some basic plant information such as operating authority, construction, and/or most recent renovation. The database is designed to complement the Municipal Water Pricing database maintained by Environment Canada.

2. Data Sources

There were three main sources of data for this database. First, the basic framework and original raw data was provided from the 1986 MUNDAT database. Second, this data was corrected, revised, or updated on the basis of supplemental information collected as the result of six water pricing studies conducted by this department. These studies (in 1983, 1986, 1989, 1991, 1994, and 1996) have now directly contacted all municipalities with populations in excess of 1000. The 1996 study was very successful, with about 87 percent of the municipalities being revised. The third data source was a series of phone calls (approximately 100), in order to resolve any problems with the earlier data sources, and to collect data for new municipalities, municipal annexations, major non-respondents, and for some municipalities with major boundary changes. As 1996 was a Statistics Canada Census year, up-to-date boundary and population data was available for cross-comparison. This latter process (including the re-definition of "municipality" described at the end of this note) had the net effect of deleting 138 municipalities with a total combined population of 280 000, but with only a combined population of less than 5000 (out of 22.8 million) served by water systems.

The information presented in the database can be considered as current to December 31, 1996. Although the database is not designed for time series analysis, the previous data have been retained as separate, independent files. A future municipal water pricing study is proposed for 1999. All information from this, or any other municipal water use study, will be used to further revise this database.

3. Definitions

The definitions and basic data parameters for each column of the standard spreadsheet are presented below in a "Column/Name Criteria" format.

A. Hydrometric Area – as defined by Environment Canada, Water Survey of Canada. (alpha-numeric/ hierarchical)
B. Standard Geographic Code – as defined by Statistics Canada. Seven digit;
   Province = first two digits:
   10 = Newfoundland
   11 = Prince Edward Island
   12 = Nova Scotia
   13 = New Brunswick
   24 = Quebec
   35 = Ontario
   46 = Manitoba
   47 = Saskatchewan
   48 = Alberta
   59 = British Columbia
   60 = Yukon
   61 = Northwest Territories,
      Census Division (3-digit), Subdivision (3-digit).
C. Municipality – as listed by Statistics Canada. The population cut-off is at 1000. (Individual municipal water/wastewater systems within municipal areas are entered if they serve more than 200 people.) Most rural areas, such as townships or parishes, are not included. (Exception to preceding; some parts of Census Metropolitan Areas (CMA's), or Census Agglomerations (CA's) with populations in excess of 1000 are included, see note at end.) When a municipal population has fallen below 1000, the municipal name is enclosed in brackets for one survey update. In some cases old municipal names (in brackets) may follow new names to reduce confusion. In the municipal water pricing database, separate area names (in brackets) identify areas within municipalities with differing water rates. The database does not list unincorporated areas as municipalities.
D. Date Revised – most recent revision.
E. Present Population – from the municipality, may not agree with the most recent census.

F. C.M.A., C.A. Codes – Census Metropolitan or Census Agglomeration area codes, as defined by Statistic Canada.
G. Size Group Code – groups are: 1 (less than 1000 population), 2 (population 1000-1999), 3 (population 2000-4999), 4 (population 5000-49 999), 5 (population 50 000-499 999), and, 6 (population 500 000 plus). A few "declining" municipalities with populations less than 1000 are retained as size group "1" in the interest of consistency across survey years.
H. 1996 population – from Statistics Canada Census.
I. 1991 population – as above.
J. 1986 population – as above.
K. 1981 population – as above.
L. 1976 population – as above.
M. 1971 population – as above.
N. Population Served, Water – population in the municipality served by any water system. Does not include population external to the municipality. Does not include private individual groundwater supplies.
O. Population Served, Sewers – population in the municipality served by any sewer system. Does not include population external to the municipality. (In Northern Canada, includes municipal pumpouts.)
P. Population Served, Sewage Treatment – population in the municipality served by any type of sewage treatment. Does not include population external to the municipality. Does not include private individual septic tanks, and/or tile fields.
Q. Average Daily Flow (A.D.F.), Water – in the municipality from all sources, in cubic metres per day. Does not include water provided to other municipalities.
R. Maximum Daily Flow (M.D.F.), Water – non-additive value of the flow on the maximum day. In cubic metres. In the case of a municipality supplying water to other areas, this is the total for all areas. The actual day will also vary for different municipalities. Non-additive for these two reasons. New in 1996 survey.
S. Average Daily Flow (A.D.F.), Treated Sewage – includes only the sewage from the municipality. In cubic metres per day. Includes only the volume of sewage which receives treatment. Due to the difficulties of sewage metering, and a general lack of volume detail on the part of some municipalities, this value has been estimated in some cases.
T. Degree of Domestic Water Metering, as a percentage of the population served – (N.A. means not applicable, there is no municipal water system.)
U. Water Use, Domestic -- a municipal estimate of the total A.D.F. used for domestic purposes. In cubic metres per day.
V. Water Use, Commercial and Institutional – as above.
W. Water Use, Industrial – as above.
X. Water Use, Other – as above. Includes system losses and unaccounted. In earlier surveys, includes all flows from municipalities that were unable to estimate the preceding user classes. Note, this value is believed to be often under-reported.
Y. Groundwater Only – the population in the municipality, which is served exclusively by municipal groundwater system(s) (wells). Does not include private individual wells.

Z. Combined Surface and Groundwater – as above, but includes some surface supply (lake, river, etc.) also feeding into the municipal system. (All remaining serviced population is thus serviced exclusively by surface sources). See also Note 2 at end. Groundwater Only, A.D.F. – the Average Daily Flow for the "Groundwater Only" criteria above.

AA. Groundwater Only, A.D.F. – the Average Daily Flow for the "Groundwater Only" criteria above.

AB. Combined Surface and Groundwater, A.D.F. – as above.

AC. Population With No Sewage Treatment – all population in the municipality without any servicing by a sewage treatment plant (STP).

AD. Primary – all population in the municipality served only by any form of mechanical sewage treatment. Does not double count population served by more advanced methods.

AE. Waste Stabilisation Ponds – all population in the municipality served only by W.S.P.'s (also called "lagoons"). This treatment type can achieve treatment levels equal to the following "Secondary" treatment level, however there is no double counting between the two levels.

AF. Secondary – all population in the municipality served only by biological sewage treatment. An assumption is made that any secondary STP is actually operating at a higher level of pollution reduction than a primary STP. The "Primary and Tertiary" combined type of STP is usually counted as secondary. Municipal septic tanks are assumed to be operating correctly, and providing a secondary level of service.

AG. Tertiary – all population in the municipality served only by some form of sewage treatment providing a higher level of treatment than secondary. Usually includes effluent polishing, phosphate removal, and sometimes, spray irrigation. Does not double count population in the preceding columns.

AH. Rural Population Served, Water – the population in nearby non-surveyed areas served by the municipal water system(s). This value is "rural" population, and is not included anywhere else in the database. (The Canada total is 227 727 or +0.9% of the database population).

AI. Rural Population Served, Sewers – same criteria as above, except the data applies to the municipal sewer system(s). (70 299, +0.3%).

AJ. Rural Population Served, Sewage Treatment – as above, except the data applies to the municipal sewage treatment plant(s). (87 954, +0.3%).

AK. Problems, Water Quantity – the range of years (i.e., '94-'96) during which the municipality has experienced supply quantity problems.

AL. Problems, Water Quantity – as above, except lists the number of years.

AM. Problems, Water Quality – the range of years during which the municipality has experienced water supply quality problems.

AN. Problems, Water Quality – as above, except lists the number of years.

AO. Notes – most of these relate to the "problems" in columns AK and AL.

AP. Use Restrictions – number of days in calendar 1995 when the municipality imposed water quantity restrictions.

AQ. Boil Days – as above, quality restrictions.

AR-AW.

Effluent Disinfection –"Y"es answers to type of sewage disinfection after the sewage treatment stage. Possibilities: none, chlorinating, dechlorination, ozone, ultraviolet, or other.

AX-BC.

BOD5 removal rate (%) and BOD5 30 day effluent average (mg/l) for largest three sewage treatment plants. New in 1996 survey.

BD-BF.

Effluent discharge –"Y"es answers to freshwater, marine, or other. In rare cases, two types are possible. ("Ground infiltration" entered as "freshwater and other", "tidal river/estuary" entered as "marine and other".) New in 1996.

BG-BM.

Water Disinfection –"Y"es answers to type(s) of water disinfection. Possibilities: none, chlorination, chloramination, chlorine dioxide, ozone, ultraviolet, or other. Question has been simplified since 1994.

BN. Alum –"Y"es or "N"o answer to use of aluminium base coagulant in water treatment.

BO. Fluoridation – as above, fluoride addition.

BP. Fl. Raw – fluoride concentration (PPM) in raw water. Not revised in 1996.

BQ. Fl. Treated – as above, treated water. Not revised in 1996.

BR. Frequency – number of times per year the fluoride is monitored. Not revised in 1996.

BS. Fl. Start – date, year/month fluoride started. Not revised in 1996.

BT. Fl. End – as above, fluoride ended. Not revised in 1996.

BU. Hi. Nat. Fl. – municipalities which reported a requirement to reduce the fluoride in raw water. There were no responses to this question in 1994. Not revised in 1996.

BV-CN.

"Y"es answers to a variety of water treatment types. Types: none, pre-treatment by micro straining, flocculation and coagulation, sedimentation, flotation, slow sand filtration (not revised in 1996), rapid sand (dual/multi media) filtration (not revised in 1996), sand filtration (includes previous two categories), activated carbon (T.&O.), pH correction, corrosion control, iron or manganese removal, pressure filtration (not revised in 1996), biological active filtration (not revised in 1996), membrane filtration (not revised in 1996), ion exchange (not revised in 1996), sequestering (not revised in 1996, usually same as iron or manganese removal), taste and odour (not revised in 1996, usually the same as activated carbon), and other. Note, some of the preceding have changed in order of presentation since 1994.

CO. First Water Treatment Plant – the reporting authority for the largest (in terms of A.D.F.) municipal water treatment plant. Can be "SELF" (own municipality), a "S.G.C." (of an other municipality), or "NONE". In the case of multiple plants, the first three letters of the plant name are used. Thus "SELF-MAI"(n), and "SELF-OTH"(er).

CP. Year Built – expressed as a calendar year, earliest possible entry is '01.

CQ. Last Renovation – expressed as a calendar year, for last major renovation.

CR-DF.

A series of repetitive columns similar to the preceding three columns for the "First Sewage Treatment Plant", "Second Water Treatment Plant", etc. A maximum of three water and sewage plants is possible for each municipality.

DG. Use restrictions – number of days in 1993 when the municipality imposed water restrictions.

DH. Boil Days – as above.

DI-DJ.

Latitude and Longitude for each municipality. Source is usually "Gazetteer of Canada".

4. Supplemental notes to the 1996 update

   1. It has always been the intention of this database to cover all areas where there are, or could possibly be, municipal water or wastewater services. The 1996 database surveys municipalities with a total population of 24.7 million, of which 22.8 million are served by municipal water systems. The 1996 Canadian Census conducted by Statistics Canada showed an urban population of 22.5 million. About 20 to 25% of the Canadian population lives in rural surroundings, much of which is unlikely to ever be provided with municipal piped services. The actual legal definitions of "City", "Village", "Town", etc. are set by each province, and in some cases may contain what would otherwise be called "rural" population. The selection of areas for the database has always assumed that where there is a legal incorporation of a municipal area, then there is also some sort of administration, and at least the possibility of municipal services. This is not always so.
   2. The database has also included components of Statistics Canada's "Census Metropolitan" and "Census Agglomeration" areas (if over 1000 population) as these areas are close to major municipal systems, and might logically be expected to be serviced. Since one of the major definitions of C.M.A.'s or C.A.'s is based on percentage of people working (i.e., commuting) in the central area, large areas which would otherwise be considered as "rural" have also been included in the MUD database.
   3. In order to improve the database definition of "urban" all of the preceding possibly rural areas were compared with Statistics Canada data under the following criteria: if the area had over 5000 population it was retained, or, was discarded if the population density was less than 30 per square kilometre AND the area had historically never had more than 1000 population served by water or sewer services. This correction resulted in the deletion of 66 "municipalities" which provided water services to about 9000 population in total. About 5500 of this population appears in the "rural population" column (AH), so the actual loss of data is for about 3500 people out of a total of 22 300 000 served by water services.
   4. The question regarding "combined surface and groundwater systems" was improved by asking for the percentage of each. When this could be answered, the proportion of groundwater was entered as groundwater only. It is believed that this is a more accurate measure of groundwater use. The effect of this revision is to move about 1 100 000 people out of the "combined" category, of which about 600 000 appear in the groundwater category.
   5. In a few cases the sewage categories were adjusted on the basis of BOD5 information first asked for in 1996. This change is believed to have had minimal effects.
   6. Aboriginal population. In many cases during the1991 Statistics Canada Census, access was not available, or enumeration was incomplete for residents of various aboriginal communities. This deficiency was mostly corrected in the 1996

A. Hydrometric Area – as defined by Environment Canada, Water Survey of Canada. (alpha-numeric/ hierarchical).

B. 1991 Standard Geographic Code – as defined by Statistics Canada. Seven digit; Province = first two digits:

10 = Newfoundland
11 = Prince Edward Island
12 = Nova Scotia
13 = New Brunswick
24 = Quebec
35 = Ontario
46 = Manitoba
47 = Saskatchewan
48 = Alberta
59 = British Columbia
60 = Yukon
61 = Northwest Territories,
Census Division (3-digit), Subdivision (3-digit).

C. Municipality – as listed by Statistics Canada. The population cut-off is at 1000. (Individual municipal water/wastewater systems within municipal areas are entered if they serve more than 200 people). Most rural areas, such as townships or parishes, are not included. (Exception to preceding; some parts of Census Metropolitan Areas (CMA's), or Census Agglomerations (CA's) with populations in excess of 1000 are included). When a municipal population has fallen below 1000, the municipal name is enclosed in brackets for one survey update. In some cases old municipal names (in brackets) may follow new names to reduce confusion. In the municipal water pricing database, separate area names (in brackets) identify areas within municipalities with differing water rates. The database does not list unincorporated areas as municipalities.

D. Date Revised – most recent revision.

E. Present Population – from the municipality, may not agree with the most recent census.

F. C.M.A., C.A. Codes – Census Metropolitan or Census Agglomeration area codes, as defined by Statistic Canada.

G. Size Group Code – groups are: 1 (less than 1000 population), 2 (population 1000-1999), 3 (population 2000-4999), 4 (population 5000-49 999), 5 (population 50 000-499 999), and 6 (population 500 000 plus). A few "declining" municipalities with populations less than 1000 are retained as size group "1" in the interest of consistency across survey years.

H. 1996 population – from Statistics Canada Census.

I. 1991 population – as above.

J. 1986 population – as above.

K. 1981 Population – as above.

L. 1976 Population – as above.

M. 1971 Population – as above.

N. Population Served, Water – population in the municipality served by any water system. Does not include population external to the municipality. Does not include private individual groundwater supplies.

O. Population Served, Sewers – population in the municipality served by any sewer system. Does not include population external to the municipality. (In Northern Canada, includes municipal pumpouts.)
P. Population Served, Sewage Treatment – population in the municipality served by any type of sewage treatment. Does not include population external to the municipality. Does not include private individual septic tanks, and/or tile fields.
Q. Average Daily Flow (A.D.F.), Water – in the municipality from all sources, in cubic metres per day. Does not include water provided to other municipalities.
R. Maximum Daily Flow (M.D.F.), Water – non additive value of the flow on the maximum day. In cubic metres. In the case of a municipality supplying water to other areas, this is the total for all areas. The actual day will also vary for different municipalities. Non-additive for these two reasons. New in 1996 survey.
S. Average Daily Flow (A.D.F.), Treated Sewage – includes only the sewage from the municipality. In cubic metres per day. Includes only the volume of sewage which receives treatment. Due to the difficulties of sewage metering, and a general lack of volume detail on the part of some municipalities, this value has been estimated in some cases.
T. Degree of Domestic Water Metering, as a percentage of the population served –(N.A. means not applicable, there is no municipal water system.)
U. Water Use, Domestic – a municipal estimate of the total A.D.F. used for domestic purposes. In cubic metres per day.
V. Water Use, Commercial and Institutional – as above.
W. Water Use, Industrial – as above.
X. Water Use, Other – as above. Includes system losses, and unaccounted. In earlier surveys, includes all flows from municipalities that were unable to estimate the preceding user classes. Note, this value is believed to be often under-reported.
Y. Groundwater Only – the population in the municipality which is served exclusively by municipal groundwater system(s) (wells). Does not include private individual wells.
Z. Combined Surface and Groundwater – as above, but includes some surface supply (lake, river, etc.) also feeding into the municipal system. (All remaining serviced population is thus serviced exclusively by surface sources.).
AA. Groundwater Only, A.D.F. – the Average Daily Flow for the "Groundwater Only" criteria above.
AB. Combined Surface and Groundwater, A.D.F. – as above.
AC. Rate indicator – **R**esidential, **C**ommercial, **N**on **R**espondent, or No Water System.
AD. Rate type – **Flat**, **D**eclining **B**lock **R**ate, **C**onstant Unit **C**harge, **I**ncreasing **B**lock **R**ate, **Complex,** **N**on **R**espondent, or **N**ot **A**pplicable.
AE. **A**ssessment/**N**o **W**ater **U**sed – an indicator if the rate is based solely on municipal property assessments, or if there is no municipal system. Pricing data for systems serving less than 200 population was generally not entered.
AF. Constant Unit Price – price for one cubic metre.
AG. First Block Price – price for one cubic metre at the first (i.e., lowest use) priced block.
AH. Last Block Price – as above.
AI. Number of Blocks – excludes any flat rate/minimum (i.e., non unit priced) block.
AJ. Upper Limit, First Block – in cubic metres per month.

AK. Lower Limit, Last Block – as above.
AL. Minimum Monthly Meter/Sewer Charge – any flat rate/minimum block charge. Includes (if applicable) a ¾ inch residential meter charge, or a 1 inch commercial meter charge. Includes "flat sewer charge". See column AO.
AM. Volume Included in Minimum Charge – in cubic metres per month.
AN. % Sewer Charge – the percentage of all monthly price information derived from a sewer surcharge component. For example 33% means that one-third of the values in columns AQ to BH were used to pay for sewage. In the cases of block rate sewer charges, the lowest block rate was used.
AO. Flat Sewer Charge – the monthly price of any flat sewer charges (or "minimum sewer charge"). Note: this value is also included in the "minimum monthly meter/sewer charge" column AL.
AP. B.O.D. Criteria – "Y"es/blank response as to whether the municipality has any type of regular charge based on direct effluent monitoring. These charges usually apply to one (or a few) specific industrial users and can be very complex, with B.O.D. being only one component.
AQ to AY.
Derived Residential Charges – series of derived residential charges (total, average, and marginal) at 10, 25 and 35 cubic meters per month including all minimum charges.
AZ to BH.
Derived Commercial Charges – series of derived commercial charges, at 10, 35 and 100 cubic meters per month.
BI to BG.
Latitude and Longitude for each municipality. Source is usually "Gazetteer of Canada".

Note: Environment Canada also holds some other data on municipal water and wastewater infrastructure. The following information on a similar spreadsheet basis is available from valerie.sexton@ec.gc.ca .

1. Sewage treatment type (e.g., primary, secondary, etc.), also BOD5.
2. Problems related to water quantity/quality, years of occurrence.
3. Water use restrictions/boil days.
4. Water and wastewater disinfection.
5. Effluent discharge area (freshwater, marine, other).
6. Some water treatment items, such as use of alum, fluorine.
7. Basic descriptive locational information on a "plant" basis.
8. Mailing addresses for surveyed municipalities plus some selected water agencies.

A small user fee may apply for some data manipulation, or for the cost recovery of supplies.

Annex 4: Regional Graphics for TRWD and Population