THE UNIVERSITY OF CALGARY

WATER AVAILABILITY AND USE IN THE CITY OF CALGARY, ALBERTA.

by

Augustine Akuoko-Asibey

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Water Availability and Use in the City of Calgary, Alberta," submitted by Augustine Akuoko-Asibey in partial fulfillment of the requirements for the degree of Master of Arts.

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ABSTRACT

The streamflow patterns of the Elbow and Bow Rivers in Calgary, from which the City of Calgary draws most of its surface water supply were examined for trends between 1960 and 1988. Since 1960, the annual streamflow of the two rivers have been decreasing. These changes may be due to climatic changes in the Southern part of the Province of Alberta.

In addition to the above, a seasonal model for forecasting seasonal water use for the City of Calgary has been developed and verified, with the use of Stepwise Regression Analysis. Baseline data for the short-term model were obtained for the period May-August, 1982-1985. This short-term model includes only temperature as the predictor variable. The R^2 value obtained for the short-term model is 0.66, and the overall statistic for significance of the regression equation is about 27. The study revealed also that water use in the City of Calgary remains fairly steady when temperatures are below 15°C, and tend to increase with increasing temperatures, especially when temperatures are above 15°C.

A separate model has been developed and calibrated for predicting long-term patterns of water use for the City. The long-term model includes three predictor variables: number of households per thousand population, average price of water in 1981 constant dollars and temperature, with an R^2 of 0.96 and an F-value of 149. The two models were verified with actual water use data from 1986-1989.

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DEDICATION

To my Mom and late Dad.

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CHAPTER ONE

INTRODUCTION

1.0 Introduction and rationale

The management of water resources is becoming an increasingly serious concern throughout the world, not only in developed nations but also in developing ones. The growth of population and the spread of surburbs and vacation homes, industrialization, and agricultural pressures are only a few of the major headings under which one could catalogue the reasons for the urgency being felt in the field of water resources management. Increasingly, it seems that "the water problem" can no longer be viewed simply as one of new source development or of interbasin transfers, as a matter of creating a new reservoir or digging a new canal (Bower et al., 1984). Physical and economic constraints may place obstacles in the way of water resources development, hence the need to develop water management strategies to ensure efficient management of water.

The City of Calgary in Alberta has developed resource management strategies, in the form of leak detection and repair, water main replacement and maintenance, and the education of water users on the need for water conservation. Despite the importance of such measures, sufficient attention has not been given to the study of the nature of water supply sources and demand, and to examining and evaluating the factors influencing water use in the City. In the light of this, some relevant issues need to be addressed and include: (1) what is the nature of the water supply sources to the City, (2) what factors are responsible for the City's water use, and (3) how can the variability of future water use be determined? These issues are addressed in this study.

The City of Calgary was selected for the study because of the availability of required information and because the above subject has not been researched by the City. It is hoped that the results of the study will give water resource managers in the City additional information for the design and implementation of short- and long-term water resource policies and will serve also as a guide to future water use studies, not only in the this city but also in other urban areas.

1.1 Objectives of the thesis

The primary objectives of this thesis are:

(a) to examine the trend in the natural streamflow patterns of the Bow and Elbow Rivers. The purpose is to determine if supply is adequate to meet future consumption in the City of Calgary.

(b) to analyze the existing water consumption for the City of Calgary.

(c) to examine the climatic and socioeconomic factors which affect the City of Calgary's water consumption and to evaluate them. The technique applied for the evaluation is Stepwise Regression.

(d) to verify if the factors identified in (c) could be used to determine the future variability of water use in the City.

1.2 Organization of the thesis

The organization of the remaining chapters of the thesis is as follows:

Chapter Two deals with the relationship between urban-growth and water supply. This chapter provides an historic overview of the role of water in urban growth and provides an overview of current urban water problems on a global scale.

Chapter Three examines the water supply sources of the City of Calgary to determine the relative abundance or lack of water. Surface sources only are considered as groundwater is not an important source of supply in the City.

Chapter Four provides an analysis of existing water consumption patterns in the City of Calgary. Such an analysis is important to water resource managers because it helps to identify the nature of the water consumption pattern in the city, that is, whether total water consumption has been increasing or decreasing over the years.

Chapter Five deals with the sources of data, the technique used in evaluating the factors and the criteria for the analysis of the data.

Chapter Six involves both an examination and evaluation (with the use of Stepwise Regression Analysis) of the climatic and socioeconomic factors that are expected to have significant effects on water use in the City of Calgary.

Chapter Seven provides a brief conclusion and recommendations. Separate summaries are provided at the end of each chapter.

CHAPTER TWO

THE OUTLOOK FOR WATER.

2.0 Introduction

The rapidly changing patterns of water use and the related pollution problems in urban areas indicate that humanity is in a transition phase from the days when it was assumed that water was plentiful to an immediate future in which use will be governed by increasing scarcity in various urban centres. Although urbanization and water have been linked historically, the relationship between cities and water has been divided into four concerns; viz, water front landuse, water-related recreation and open space, water quality and quantity management, and urban growth (Raven-Hansen, 1969; World Resources Institute, 1988). The first three concerns have been dealt with by planners, engineers and water resource analysts. The fourth concern of urban- growth /water supply management has received little attention in the geographic literature.

This chapter serves to address this fourth concern. The chapter is divided into four sections. The first section provides a global historic overview of the role of water in urban growth. The second section provides a global overview of contemporary water problems in urban areas. The third section explores the trend in both the world's and Canada's patterns of water use and also attempts to assess the urban water supply and demand relationships, both worldwide and in the Canadian context. The aim is to discard the “water is plentiful” notion because of the disparities in the availability of water resources both regionally and nationally. A general overview of the Calgary water supply environment comprises the fourth section, while the final section provides a summary to the chapter.

2.1 Urbanization and water resources

Water has played an important role in national economies. Many centuries before the Christian era, vast irrigation diversion works were built on the Nile, Euphrates and Tigris rivers of the arid plains of Egypt, Assyria and other countries. Evidence of these early river-control works still exist (Dridan, 1964; Fukuda, 1976).

Water became a symbol of opulence in the cities of the Great Roman Empire at the height of its power and was used lavishly by the privileged classes for bathing and aesthetic purposes. Although the Roman water systems exhibited defects relative to current standards, they were a central feature of the Roman social system as indicated by the prominence of the elaborate public baths (Hansen, 1983).

Water fills such an important role in the life of any urban community today that it seems strange for written histories of Medieval times and of the Renaissance to make little reference to the use of this essential resource. One reason may be that past communities required a smaller water supply than do today's communities. No reticulated water was used to carry human and other wastes away from cities, very little was used for personal hygiene, and most waters were so polluted that their use for drinking purposes without prior treatment was viewed with disfavor (Dridan, 1964). Some of the large European cities placed a great deal of attention on the provision of water supplies. Practically all cities, such as London-upon-Thames, were established on the banks of rivers so that the inhabitants could draw water from these streams.

As cities grew it was necessary to look further afield for adequate supplies. The London City Corporation, for example, embarked on its first water supply scheme in the year 1237, and constructed a lead pipeline to carry water from springs at Yyburn to conduit heads in the City, from which the inhabitants carted their water. With the rapid increase in building in London and the work of James Watt in developing improved pumping machinery, intense interest developed in water-supply works. However, it was not until 1902 that the London Water Board was set up under the Metropolis Water Act. In 1947 the

Board supplied an average of 332 million gallons a day to a population of 6,280,000 representing an average daily per capita consumption of 53 gallons (Dridan, 1964).

The pattern of development of water supplies in Canadian towns and cities has closely followed the experience in other countries. Most Canadian towns and cities were also established on the banks of permanent streams, or streams that were thought to be permanent. Typical examples are the cities of Calgary (located on the confluence of the Bow and Elbow Rivers), Montreal (on the St. Lawrence River), Vancouver (on the Fraser River) and Edmonton (located on the North Saskatchewan River). The carting of water from these rivers by individual efforts was followed by the provision of reticulated supplies by properly constituted Government or local government authorities.

While it is logical to assume that increasing populations will call for greater water supplies, the disturbing fact is the continual increase in consumption per capita. This, in effect, means that every inhabitant of an urban area is using more water, and higher capital and operating expenditures are necessary to meet each increment of demand. Although population growth is one relatively crude measure among many important factors that could affect a country's water situation, Global 2000 concluded that: "population growth will be the single most important cause of increased future demand" (United States Council on Environmental Quality and State Department, 1980, pp. 152-157).

2.2 Contemporary water problems in urban areas

Just as water has played a significant role in the historical growth of cities, water is an important factor in current development processes in urban areas. However, urban development may be hindered by problems in the water industry. Both increasing urbanization and the continued growth of megacities pose serious actual and potential adverse effects on water quantity and quality in urban centres (World Resources Institute, 1988). Water management problems constraining urban development range from inadequacies in the supply of domestic water to inadequate control over such negative impacts as flooding. Serious water shortages at certain geographic locations may be accompanied simultaneously by major flooding at other locations. For example, while the people of Bamako in Mali were experiencing severe water shortages in the early 1970s, the people of Dhaka in Bangladesh were experiencing major flooding at the same time (Hewitt, 1983).

Most often severe water shortages in small countries such as Mali, Chad, Niger and other North African countries receive the most attention in the water resources literature (World Health Organization [WHO] and United Nations Environmental Program [UNEP], 1990). However, some developed countries encounter severe problems which have the potential to become worse. In the United States, for example, real water shortages are being experienced, especially in the West. In the Colorado River Basin, the seven states (Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming) that share the basin have already committed virtually all of the river's flow to use. In the Mid-West, the Olagalla aquifer has been overdrawn to the extent that irrigators and other users experience shortages. There is no surplus for further allocation, and long-term scarcity is inevitable (Foster and Sewell, 1981; Organization for Economic Co-operation and Development [OECD], 1989). Similar water shortages have been experienced in Spain and Turkey (OECD, 1985) and Greece (OECD, 1989).

Such shortages often result in the adoption of harsh measures to deal with the situation. A typical example is the drought which occurred in most Western States of the United States in 1976-77. This drought resulted in the Marin Municipal Water District (just north of San Francisco, California) imposing a strict fifty gallons per person per day water rationing on their customers (Matthai,1988).

Excess water also can bring widespread devastation. The occurrence of major floods sometimes is cited in the water resource literature as evidence that water resources are out of adjustment to human needs. Floods are caused by accelerated runoff which in turn renders the supply less accessible. Flood frequency in numerous urban areas undoubtedly has increased as a result of buildings, paving, and channel encroachment (United Nations Educational, Scientific and Cultural Organization [UNESCO], 1987). The City of Dhaka in Bangladesh is an area that suffers catastrophic flooding losses on a frequent recurring basis, both from overflowing rivers and from cyclones that inundate low-lying areas. In 1985, for example, at least 15,000 deaths resulted from flooding caused by a cyclone (Iyer, 1985).

Although public attention often focuses on water related disasters, many other less dramatic water problems currently pose significant impediments to urban growth and development. These less publicized water problems can be significant in terms of their chronic nature, and the number of people affected.

One of these chronic problem areas involves inadequacies in urban water supplies and sanitation, especially in urban centers in developing countries. A survey conducted by the World Health Organization revealed that in 1983, 26% of the urban population in developing countries did not have reasonable access to safe water supplies. At the same time, 47% of urban dwellers in the developing countries were not covered by sanitary services (UNEP, 1987). Added to this problem are inorganic and organic compounds, such as nitrates and high levels of fluorides, found in drinking water. These compounds affect human health if higher than safe normal levels are present in the water supply system (WHO and UNEP, 1989).

Though the launching of the International Drinking Water Supply and Sanitation Decade (1981-1990) constituted a major effort to improve water supply and sanitation conditions worldwide, by 1985 prospects that overall conditions had been substantially improved appeared poor (Wiseman, 1985; UNEP, 1987). It has been estimated that by the end of 1990 only about 79% of people in urban areas would have access to clean water, while only 62% of urban dwellers would have been covered by sanitation facilities (UNEP, 1987). This relative lack of progress may be attributed to two principal factors : (a) lower than anticipated funding for improving water supply and sanitation due to world economic conditions, and (b) rapid population growth that has expanded the number of people without service (UNESCO, 1987).

The absence of reasonable access to a safe drinking water supply has two direct impacts on the population affected: (a) excess time and energy expenditures associated with water collection, and (b) health problems associated with water collection and use. Women and children in developing countries may spend several hours each day collecting water to meet family requirements. Health problems associated with inadequate domestic water supply include diseases caused by ingestion of infective organisms and diseases associated with inadequate quantities of water for consumption and personal hygiene.

Water supply deficiencies and other water-related health problems produce impacts extending beyond the direct effects on individual members of society. Water supply is a component of a nation's socioeconomic infrastructure and water availability affects various elements of development. For example, industrial growth, which generally is considered a key component of development, depends to some extent on water (as well as variety of other factors, such as raw material availability, capital and labour). Industrial water demand is often met in urban areas from public supplies, with the result that deficiencies in such supplies have potential to impede the industrialization process (UNESCO, 1987). Such a situation is likely to become worse in developing countries undergoing moderate to rapid industrialization (WHO and UNEP, 1990).

Water quality is another chronic problem facing many urban areas. Water quality problems are becoming more widespread and complex, ranging from pollution in the Rhine River and salinisation in Australia to acidification in Canada and Nordic countries. Contamination of shellfishing areas caused by river pollution flowing into estuaries is apparent along the French coast (OECD, 1989). Such a diversity of water problems can have consequences for a wide range of water resource users and can make water management issues complex.

2.3 Trends in water use

Despite the foregoing problems in the water resource industry, water has been tapped to supply homes and small industries for centuries. For most of humanity's history, water use has expanded at a moderate pace. Since the 1900s, however, demand has increased with rapid industrialization and the need to feed an expanding world population. According to estimates prepared by Soviet scientists in the early 1970s for the United Nations International Hydrological Decade (1965-1974), global water use in 1900 was 400 billion cubic meters or 242 m^3 per person per year. By 1940 global use had doubled, while population had increased about 40% (Figure 2-1). A rapid rise in water demand then began at mid-century. By 1970 annual per capita water withdrawals had climbed to over $700m^3$, 60% higher than 1950.

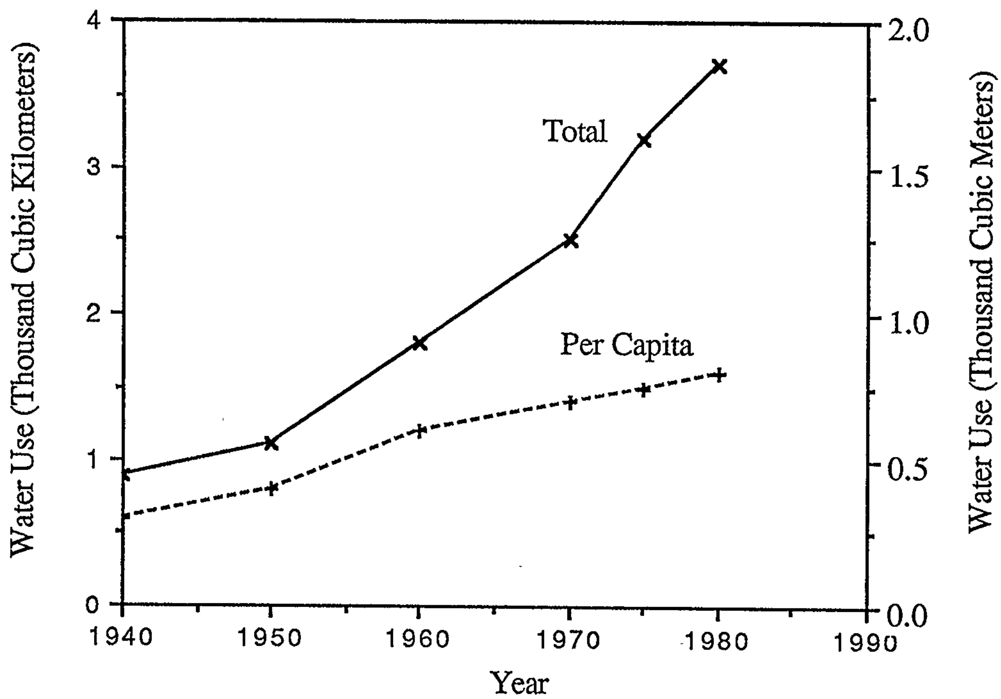

Fig. 2-1. World Water Use, Total and Per Capita, 1940-1980.

Source: Postel, 1984, p. 12.

With such a rapid increase in world water use and the expected doubling of the world's population in the next 50 years, some experts question whether we are on the brink of a widespread water crisis (Roger, 1983; Postel, 1984). From this perspective, then, an eventual water shortage worldwide can be considered as imminent. This does not have to be the outcome. Just as the global community began to appreciate the value of petroleum more after the 1970s oil crisis, today we must start looking at water from a different economic and ecological perspective. This means that we can no longer afford to consider water a virtually free resource to use as much as we like and in any way we want (Rogers, 1986).

It is important to note that the spectrum of uses varies from region to region according to climatic and socio-economic conditions. In this sense, analyzing outlooks for water on large scales, such as for the whole world or international river basins, is a difficult problem. A comparison of the per capita withdrawal figures of certain selected countries with the over-all physical and economic conditions of these countries leads to the conclusion that the highest yearly per capita withdrawals occur in countries where either irrigated agriculture or industry or both are highly developed (Table 2-1). The low percentage share of industrial withdrawals to total water withdrawals for high population countries of India and China (4 and 7% respectively) suggests, however, that heavy industrial development in these countries in the future may lead to extremely high water demands. It should be noted that the figures in Table 2-1 are subject to uncertainties due to differences in supply patterns and/or different interpretations of the concepts and categories involved.

Table 2-1

Estimated Water Use in Selected Countries, Total, Per Capita and by Sector, 1980.

Country	Water Withdrawal: Total (km^3 per year) (Billion L)	Water Withdrawal: Per Capita (m^3 per year) (1000 L)	Sectoral Withdrawal (%): Agriculture	Sectoral Withdrawal (%): Industrial	Sectoral Withdrawal (%): Municipal
United Kingdom	28.35	507	1	79	21
United States	467.00	2162	42	46	12
Canada	36.15	1501	11	71	18
Soviet Union	353.00	4	64	31	6
Japan	107.80	923	50	33	17
Greece	7.00	726	83	6	11
India	380.00	612	93	4	3
Poland	16.80	472	21	62	17
China	460.00	462	87	7	6
Madagascar	16.30	1675	99	0	1
New Zealand	1.20	379	14	11	52
Iraq	42.80	4575	95	3	2
Bulgaria	14.18	1600	71	15	14
Egypt	56.40	1202	88	5	7

Source: World Resources Institute (1988, p. 318-319).

2.3.1 Water use trends in Canada

Canada's water use trend follows the worldwide trend, showing a tremendous increase over the years. For example, between the period 1972 -1981, Canadian water withdrawals underwent increases both nationally and regionally. Nationally surveyed withdrawals grew from 24,057 million cubic meters in 1972 to 37,254 million cubic meters in 1981, an increase of 55% over the ten-year period. Regionally, the major users, Ontario, Quebec and British Columbia, followed this same ten-year trend, while the Prairie and the Atlantic regions experienced increased withdrawals during 1976 -1981 (Environment Canada, 1985).

Ontario was the major water user, accounting for 45% of all withdrawals in 1972 and more than 56% in 1981. The Prairie Region ranked second in withdrawals, accounting for 21% in 1972 and 14% in 1981. While these figures illustrate that Prairie withdrawals decreased as a proportion of national withdrawals, water withdrawals on the Prairies actually increased from 5,086 million cubic meters in 1972 to 5,342 million cubic meters in 1981. Similarly, the use of water as a proportion of national use decreased between 1972 and 1981 in the Atlantic and Quebec Regions, even though both regions showed an increase in actual water use. This phenomenon was attributed to the major growth in water withdrawals for thermal generation in Ontario which overshadowed the increases in all other uses (Environment Canada, 1985). Nationally, municipal water use rose from 3,157 million cubic meters in 1972 to 4,263 million cubic meters in 1981 (Table 2.2), representing an increase of 35% (Environment Canada, 1975; 1977; 1985). The trend toward increasing water use in Canadian municipalities may be attributed to such factors as increases in community size, the price of water, changing weather patterns and physical water losses in municipal water distribution systems (Environment Canada, 1985).

As with other international data sources, Canadian municipal water use data are variable in quantity and accuracy because most of the data are compiled from several different reports done for various regions in Canada.

Table 2-2.

Municipal Water Use in Canada, 1972, 1974 and 1981 (in million cubic meters per annum).

Province	a 1972	b 1974	% change 1972-1974	c 1981	% change 1974-1981
Newfoundland	63.8	66.7	4.5	75	12.4
Prince Edward Island	5.6	5.9	5.3	29	391.5
Nova Scotia	65.3	73.3	12.3	85	16.0
New Brunswick	76.4	81.0	6.1	119	46.9
Quebec	1084.4	1110.3	2.4	1379	24.2
Ontario	1136.6	1210.0	6.5	1460	20.7
Manitoba	88.7	91.5	3.2	86	-6.0
Saskatchewan	65.7	64.7	-1.5	222	243.1
Alberta	216.5	228.1	5.4	172	-24.7
British Columbia	346.0	375.1	8.4	557	48.5
N. W. Territories	2.3	2.5	8.7	-------	-------
Yukon	5.1	5.5	7.8	-------	-------
TOTAL	3156.6	3314.8	5.0	4263.0	29.0

Sources:

(a) 1972 Data, Environment Canada. Canada Water Year Book, 1975. Canadian Government Publishing Center, Ottawa, 1975, p. 104.

(b) 1974 Data, Environment Canada. Canada Water Year Book, 1976. Canadian Government Publishing Center, Ottawa, 1977, p. 66.

(c) 1981 Data, Environment Canada. Canada Water Year Book, 1985. Water Use Edition Canadian Government Publishing Center, Ottawa, 1986, p. 21.

2.3.2 Assessment of water supply and demand

Of the approximately 1,360 million cubic kilometers of water on the earth, about 97% is contained in the oceans and about 3% is on land. Although the oceans are important for such purposes as navigation, fisheries, cooling water supply, a source of water for desalination, and their role in climatological processes, ocean water is not readily available for satisfying many of humanity's needs. Of the 3% of water found on land, some 77% is stored in ice caps and glaciers, 22% in groundwater, and the remaining 1% is present in lakes, rivers and streams. Fresh water resources are of immediate significance for many water using activities since a substantial proportion of the groundwater stock lies below 800 meters indepth, and is beyond humanity's capacity to exploit them readily (UNESCO, 1987; UNEP, 1987).

Worldwide runoff, a measure of supply of freshwater resources, amounts to approximately 42,500 km^3 annually. Since this quantity greatly exceeds global demand of between 2,500 - 4,000 km^3 annually , shortfalls in worldwide water supply will not occur for the foreseeable future (Postel, 1984; UNEP, 1987; Moore, 1989). Such estimates are of little value, however, because of the nonuniform distribution of water supply and the activities responsible for demand. In much of Africa, for instance, because many nations are located in areas of low and variable rainfall, per capita water availability is rated as low, or very low (United States Council on Environmental Quality and State Department, 1980).

Even in Canada the result of the global study is of limited value. The emerging scene with respect to water supply in Canada is one of considerable abundance from an overall national point of view but significant local and regional scarcities (Foster and Sewell, 1981; Pearse et al, 1985). Environment Canada (1982) has identified six drainage basins where current and future water demands either exceed, or are near the reliable minimum monthly flow, namely the Okanagan, Milk, North and South Saskatchewan, Red-Assiniboine, and Southern Ontario drainage basins. These six basins are the ones where water shortages are most likely to occur in the future.

The supply and demand imbalances identified above are expected to continue into the future, and can be expected to grow if demands continue to increase. Water use conflicts will increase as a result. Under these conditions water supply will become a limiting factor in economic development. However, projections of water demand are not generally available at a level of detail adequate for meaningful assessments of supply (UNESCO, 1987). On a global scale supplies will remain much in excess of demand.

Total renewable supplies have been estimated to be adequate for meeting the needs of five to ten times the existing population (Postel, 1984). Because such estimates are of little real value, the frequent occurrence of local and regional shortages within broader areas of relative abundance indicates that water management will become an increasingly important activity in most nations.

2.4 The Calgary environment

Calgary, (51^{o} N, 114^{o} W) is located approximately 80 kilometres east of the Canadian Rockies, on the confluence of the Bow and the Elbow Rivers. It has a cold temperate climate which is considerably modified by Chinook winds. The mean temperature is -8^{o}C and temperatures can drop to -40^{o}C. The summers are short and cool and the mean summer temperature is 15^{o}C.

Calgary's mean annual precipitation is 437 mm, is strongly seasonal and ranges from about 10 mm to over 1000 mm. Its mean annual number of precipitation days is 134. Twenty-four percent of its annual rainfall is received during the six coldest months, October to March. June, with 20% of the annual total, is the wettest month and December (3%) is often the driest. In the light of this, the climate of Calgary is categorized in most texts as semi-arid (Nkemdirim, 1988).

Calgary receives most of its fresh water supply from the Bow River, which originates in the Rocky mountains and flows southeastward through the city and the province of Alberta to Saskatchewan. The river serves not only as a source of municipal water supply, but also as a world class fishery and the source of water for hydro power, industrial operations, recreation and wildlife and for hundreds of thousands of acres of irrigation in Southern Alberta. Apart from these demands, some of the Bow River flow ultimately passes on to neighbouring provinces to the east, where it is equally important as a water resource.

Below normal runoff through much of this decade suggests that the water supply of the Bow River is limited (Canadian Water Resources Association, 1989). The implications of this fact are complicated because the Bow River is part of the South Saskatchewan River Basin/System, which has been declared as a basin where current and future demand either exceed, or are near the reliable minimum monthly flow (Environment Canada, 1985). Ever increasing domestic, industrial and agricultural demands for water are clear signals of potential problems in the South Saskatchewan basin. Calgary, which contains 90% of the population in the basin and whose population has been projected to reach 1.5 million by 2006 is not immune to these water problems (Alberta Environment, 1980). However, the nature of Calgary's water problem is not simply one of a limited supply where a "technological fix" is the answer. What is needed for the future is a more critical look at the integration of water resources in the overall economic and social policies of the city.

2.5 Summary

Water resources have played an important role in the development of cities. From the origins of civilization to the present, many of humanity's major achievements have involved improvements in water resources utilization. Until recently, concerns about water usually occurred only when it was not available for use in the amounts required (as in drought), and when it was over-abundant (as in floods). Today, there is a growing awareness of many other problems (like quality) involved in its use.

Water shortages plague not only the less developed countries, but also the developed ones. Added to this problem is the increased pollution of water supply sources as a result of heavy industrialization. The overall demand for water world-wide is growing at a rate several times the increase in the global population. This does not imply that the world is on the brink of severe water shortage, if we begin to value water as an "economic resource" (that is, attach "true value" to it). From a global point of view there is considerable abundance of fresh water supply but local and regional scarcities.

The City of Calgary lies not only in a semi-arid climatic zone, but also in the South Saskatchewan River Basin, where current and projected future demands for water either exceed or are near the reliable minimum monthly flow. An examination of Calgary's water supply and use patterns is essential to ensure efficient present and future management of the resource.

CHAPTER THREE

WATER SUPPLY AVAILABILITY IN THE CITY OF CALGARY

3.0 Introduction

One of the tasks of water resources managers is to assess existing surface and groundwater sources which are directly manageable within their area of operation. Such an inventory provides information on the relative abundance or lack of water to meet future consumption. However, a discussion of inventory issues has been neglected in the geographic literature. This chapter addresses this concern by inventorying sources of surface water supply to the City of Calgary.

The chapter is divided into three sections: (i) an overview of the surface water supply sources available to the City of Calgary, (ii) a trend analysis of the average annual surface streamflow patterns of the Elbow and Bow Rivers in Calgary, and (iii) an examination of the city's population projections. A brief summary ends the chapter.

3.1 Water supply sources

The City of Calgary's municipal water supply is mostly met by the Elbow and Bow Rivers (Alberta Environment, 1980). The Elbow River flows about 120 kilometers from the Opal and Misty Ranges of the Rocky Mountains, which are about 3,050 meters high, through foothills and plains into the Bow River at Calgary, which has an elevation of about 1,000 meters (Kellerhals et al., 1972).

The Bow River has its source about 7.2 kilometers east of the continental divide in the Wapatik Mountains, rising high in the glacier-fed lakes of Banff National Park, north of Lake Louise. It passes southeastward through Banff, then eastward through Calgary and eventually joins the Oldman River as part of the South Saskatchewan River Basin. The Bow River covers a drainage area of 25,400 square kilometers. Its major tributaries include the Spray, Kananaskis, Ghost, Elbow and Highwood Rivers, all of which have their headwaters in the Rocky Mountains.

There are, respectively, four and fifteen active hydrometric stations on the Elbow and Bow Rivers, with long periods of record dating as far back as 1910. For the purpose of this study, only two of the recording stations, Elbow River (Station 5BJ001) and the Bow River (Station 5BH004) at Calgary are examined. This is because reservoir inflows, which relate directly to the city's water use, changes in reservoir levels, and estimates of reservoir outflows, are calculated from these stations.

Calgary's first water supply system was built in 1889, taking water from the Bow River. This supply was supplemented from the Elbow beginning in 1903. The Glenmore Dam on the Elbow River was built in 1932, and the Glenmore Water Supply Plant began supplying water to the city from source in 1933 (Fig. 3-1). Its original total storage capacity was 52,985 million liters (42,955 acre feet). However, this has been expanded over the years, reaching its present rated capacity of 113,799 million liters (92,257 acre feet) in 1967.

In 1973, the Bearspaw Water Supply Plant went into full operation (Fig. 3-1). This marked the first time that the Bow River had been used to supply water to the city since 1933. With the installation of pre-treatment facilities in 1978, the present storage capability of the Bearspaw (approximately 341,399 million liters or 276,772 acre feet) was reached.

3.1.1 Current water licences and rate of usage

The City of Calgary is presently licensed by Alberta Environment to withdraw 108,546.42 million liters (88,000 acre feet) annually from the Elbow River at the Glenmore Water Supply Plant (Water Works Division, 1989). This represents about 95% of the rated capacity of the reservoir. This licence was marginally exceeded by an average of 2.25 % per year at the Glenmore Water Supply Plant between 1974 and 1977 (Table 3-1), due to operational problems at the Bearspaw Plant (City of Calgary Water Works Division, 1989).

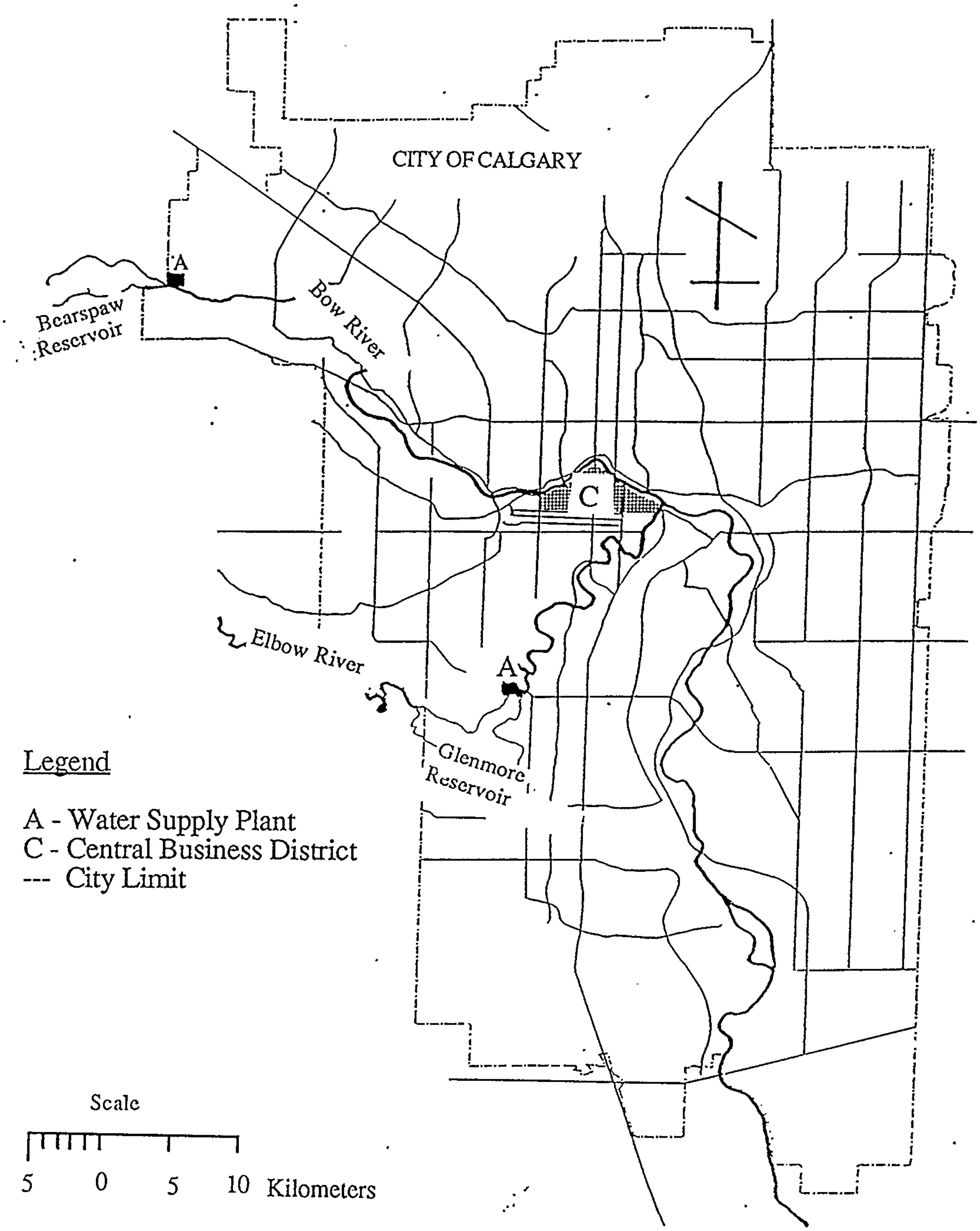

Fig. 3-1 Location of Glenmore and Bearspaw Water Supply Plants.

Since then between 84% and 95% of the licence has been used annually. In 1988, for instance, 90,866 million liters were actually withdrawn, which represents 84% of the water licence.

Table 3-1

Total Water Withdrawn from the Glenmore and Bearspaw Reservoirs to Supply the City of Calgary's Municipal Water Use in Million Liters, 1973-1988.

Year	Glenmore	% of Total Licence	Bearspaw	% of Total Licence
1973	99464	91.6	12253	8.7
1974	110150	101.6	7739	5.5
1975	110804	102.1	16226	11.5
1976	110278	101.6	24666	17.5
1977	112639	103.8	24214	17.2
1978	98620	90.8	42962	30.6
1979	92391	85.1	67418	47.9
1980	100602	92.7	59635	42.4
1981	98565	90.8	65860	46.8
1982	103631	95.5	71057	50.5
1983	103440	95.3	72503	51.6
1984	91910	84.7	88866	63.2
1985	98086	90.4	82250	58.5
1986	96312	88.7	74551	53.0
1987	101184	93.2	67595	48.1
1988	90866	83.7	75189	53.5

Source: City of Calgary Water Works Division, Long Range Planning Report,1989.

In the case of the Bow River, Calgary is currently licensed to withdraw 140,616.9 million liters (114,000 acre feet) annually, representing 41% of the Bearspaw reservoir's rated capacity. Unlike the Glenmore Plant, between 30% and 60% of the Bearspaw licence was utilized by the City between 1977 and 1988 (Table 3-1). This indicates that any future increase in municipal water demand for the city is likely to be met from the Bearspaw Water Supply Plant, unless further expansion is made to the Glenmore Plant. Since 1973 the quantity of water withdrawn from the Bearspaw Plant has been increasing compared with the Glenmore Plant (Fig. 3-2). This is due to the fact that the Glenmore Plant is being used almost to its reservoir capacity, whereas Bearspaw's rated capacity is about three times that of Glenmore, making it the Plant the City has to rely on for increased water consumption.

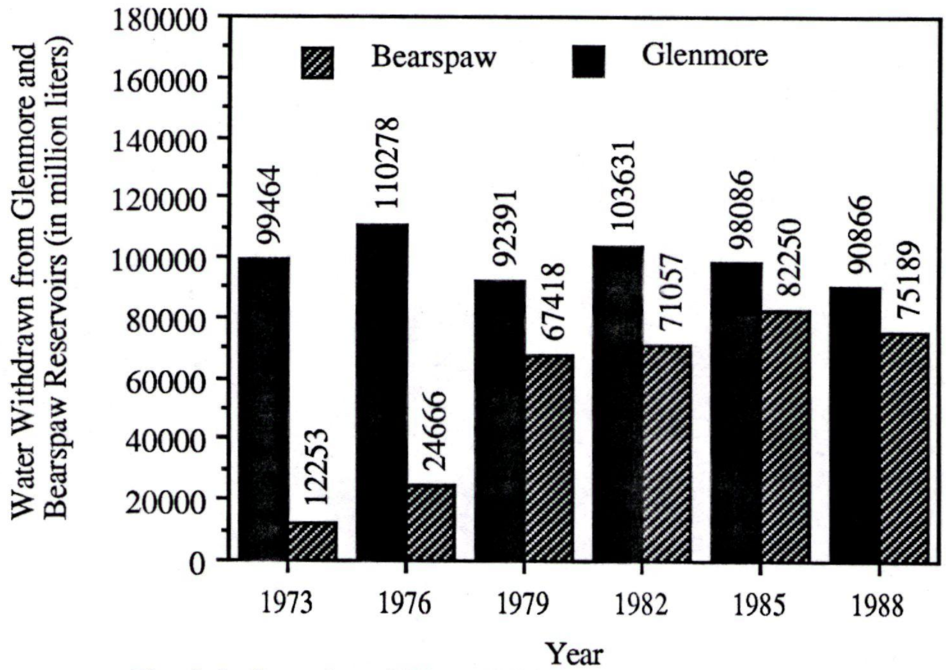

Fig. 3-2. Quantity of Water Withdrawn from the Glenmore and Bearspaw Reservoirs to Supply the City of Calgary's Water Use, 1973-1988.

Source: City of Calgary's Water Works Division, Long Range Planning Report, 1989.

3.2 Streamflow Patterns of the Elbow and Bow Rivers in Calgary

To be able to assess the amount of surface water available to the City of Calgary, it is necessary to examine hydrographs (graphs drawn to show the distribution of river or stream flow over a specified period of time) of the city's sources of surface water supply. The long term, yearly, hydrometeorological record for the Elbow and the Bow Rivers at Calgary (Stations 5BJ001 and 5BH004) from 1960-1988 illustrates the major features of the streamflow pattern. The streamflows were examined for changed trends. The results of the trend analysis are presented in two figures. The first (Fig. 3.3a) shows traces for yearly streamflow totals plus April through August streamflow for the Elbow River, in cubic decameters. April through August marks the period of snow melt in the mountains and consequent increase in streamflow and also coincides with the period of increased water use in the City of Calgary. The second (Fig. 3.3b) represents the yearly total streamflow and April through August streamflow patterns (in cubic decameters) of the Bow River in the City of Calgary. The lines are simple regression, linear best fit.

There appears to be a decreasing trend in total water year streamflow for the Elbow River over the past three decades (1960-1988) (Fig. 3-3a). The slope of the trend line for the Elbow is negative, indicating that the flow level of the Elbow River has been decreasing by an average of about 4,147 cubic decameters every year since 1960. As expected the trend in the April through August volumes is also negative with a decrease in streamflow of 3,340 cubic decameters per year on average (Fig. 3-3a). A rather pronounced decreasing streamflow occurs after 1975 for the April through August streamflow of the Elbow river. This is seen in the average streamflow of 92,874 cubic decameters between 1976 and 1988 compared with 153,287 cubic decameters between 1960 and 1975. The best fit lines for both the yearly water totals and the April through August streamflows of the Elbow River (Fig. 3-3a) are all significant at the 5% level of significance.

For the Bow River, the declining trend is less pronounced, and a decrease of 25,000 cubic decameters every year has been experienced since 1960 (Fig. 3-3b). The April-August streamflow pattern is no exception to the decreasing trend, and a decrease of about 19,000 cubic decameters has occurred, on average, every year. The trend lines of the yearly totals and the April-August streamflows of the Bow River are also statistically significant at 5% level. These imply that the decreasing trends in the streamflow patterns of the Elbow and Bow Rivers in Calgary should be of a matter of concern to the City's water managers.

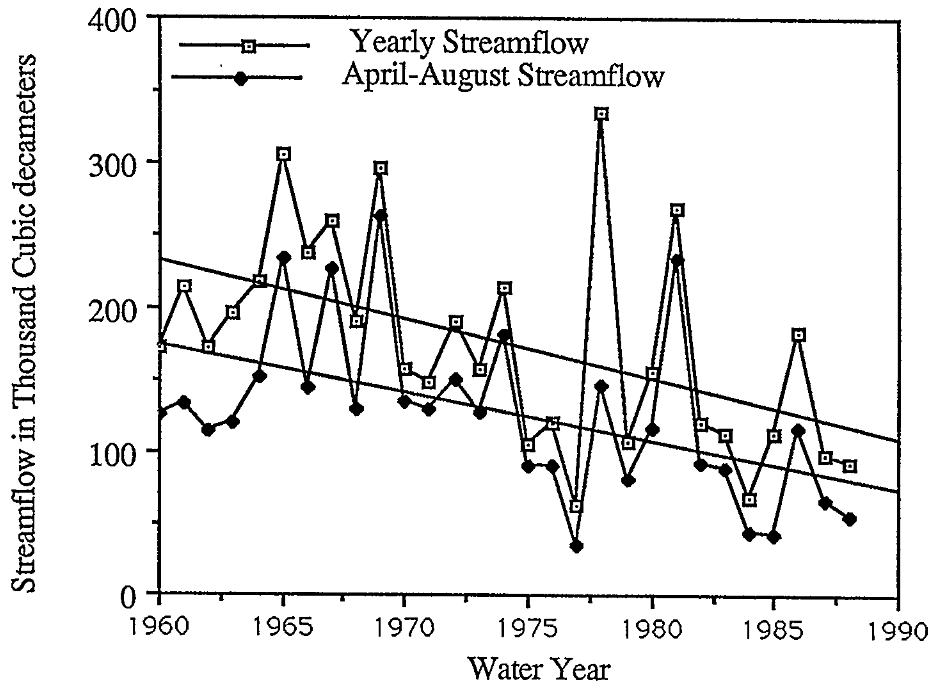

Fig. 3-3a. Elbow River Streamflow, 1960-1988.

a) Yearly streamflow, linear trend, Y = 8361.5 - 4.147X, $R^2 = 0.24$, F-value = 7.2, $\alpha = 0.05$, n = 29.
b) April-August streamflow, linear trend, Y = 6720.4 - 3.340X, R2 = 0.24, F-value = 8.4, $\alpha = 0.05$, n = 29.

In Figures 3-4a and 3-4b, the April through August totals of the annual streamflow are expressed as a percentage of the annual totals. (Note that the vertical scales are expanded and do not start at zero). These figures also show decreasing trends similar to the yearly streamflow patterns. The slope of the best-fit line for the Elbow is about -0.30 per year (Fig. 3-4a) compared with -0.16 per year for the Bow (Fig. 3-4b). These slope values (-0.30 and -0.16) indicate that there has been a average decrease of 0.30% and 0.16% in the April through August streamflow of the Elbow and Bow Rivers per year. For the Elbow River, the highest percentage (89%) of the April-August streamflow of the annual streamflow totals, which occured in 1969, did not depart markedly from the average percentage of 71, as compared with the minimum percentages in 1978 and 1985. This indicates that the decline in April-August streamflow has increased substantially since 1978.

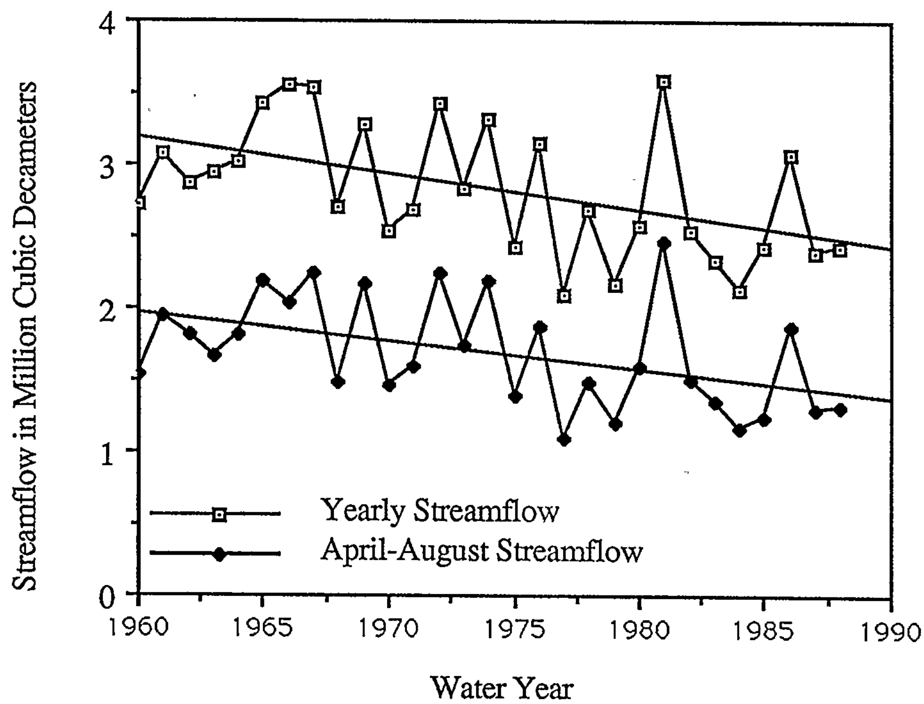

Fig. 3-3b. Bow River Streamflow, 1960-1988

a) Yearly streamflow, linear trend, Y = 52.731 - 0.025X, R^2 = 0.23, F-value = 7.8, α = 0.05, n = 29
b) April-August Streamflow, linear trend Y = 39.306 - 0.019X, R^2 = 0.185, F-value = 6.1, α = 0.05, n = 29.

Source: Environment Canada, Surface Water Data, Alberta, 1960-1988.

For both rivers, between 1975 and 1988, the April-August percentages are below their average percentage values. These are indications that the streamflows of the Elbow and Bow Rivers in Calgary have been decreasing.The decreasing trends in both the Elbow and Bow Rivers in Calgary are attributed to changing climatic conditions in the southern part of the Province of Alberta over the past two decades, and not due to over-regulation of the rivers (Spitzer, 1990). This reasoning appears valid given that the trend correlation coefficients of both streams are identical. Any differences in the rate of decline in the summer may reflect conditions in the mountains headwaters. Thus, if these trends should continue for a long period of time, they will have adverse effects on water consumption in the City, since the reservoir levels may be altered.

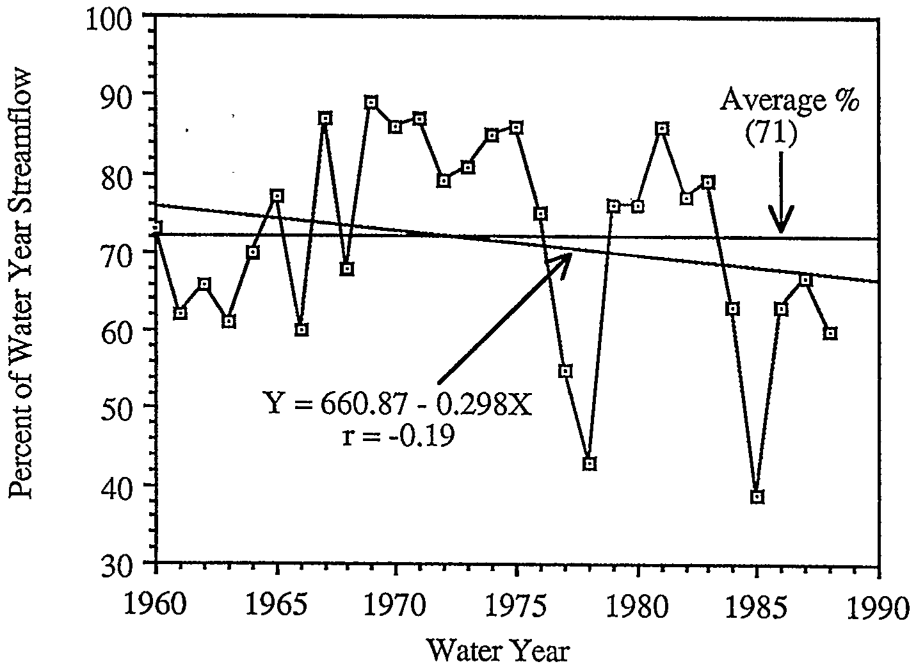

Fig. 3-4a. April-August Streamflow of the Elbow River in Percent of Water Year Streamflow, 1960-1988.

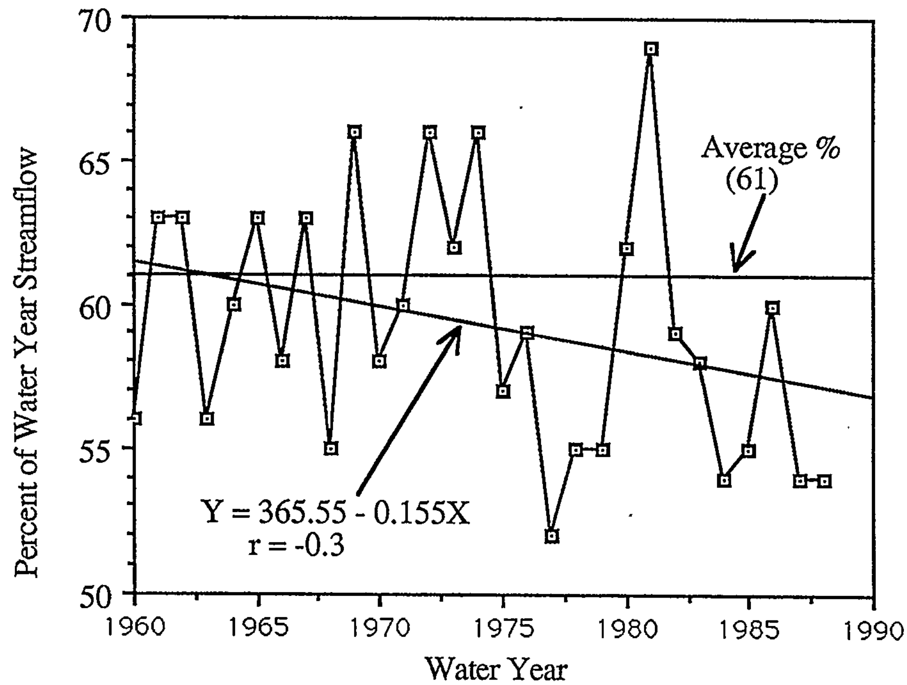

Fig. 3-4b. April-August Streamflow of the Bow River in Percent of Water Year Streamflow, 1960-1988.

3.2 Annual water yield

Having examined the pattern of streamflow of the Elbow and Bow Rivers in Calgary, it is imperative to determine the surface water yields, which is the rate at which water can be withdrawn from a reservoir without actually depleting the supply source to such an extent that withdrawal at that rate is no longer feasible for future supply (Meinzer, 1923). This kind of estimation provides the basis for changing patterns of use in the future and also of extending supplies, if required.

An assessment of the annual safe yield based on 54 years of record was carried out in 1979 by Acres Consulting Services for the two rivers, taking into account the Bearspaw and Glenmore Reservoirs. The results of their analysis are summarized in Table 3-2.

Table 3-2

Annual safe yield of the Bow and Elbow rivers in Calgary in million liters (99% reliable annual flow).

River	Safe yield
Elbow	106,697
Bow	548,899

Source: City of Calgary Engineering Department, 1980 (with modifications).

The combined 99% reliable flow of the two rivers is about one and half times the combined withdrawal licence for the two reservoirs. However, it is worthy of note that the 99% reliable flow of the Elbow river is less than its actual license of 108, 546 million liters. Thus, if the license were to be used to its maximum capacity, or if any operational problems were to occur, as happened between 1974 and 1977, the reliable source of water supply to the city would be the Bow River. Under such circumstances the application made by the city in 1981 for an increase in its Bow license would be given serious consideration (Calgary Regional Planning Commission, 1981).

3.3 Population growth and projections

Though the prime factor affecting municipal water use is population, it is beyond the control of the water resource manager. A water supply manager is typically faced with the problem of estimating future populations for a single city or a water supply district. Most managers utilize forecasts prepared by national, regional and local agencies in predicting the future water demand and in assessing the future viability of supply sources for their areas of operation. Such estimates reflect a host of economic, social, locational and political factors.

The City of Calgary's Water Works Division uses the "official" projected population figures prepared by the City's Corporate Resources Department for evaluating the future adequacy of the city's water resource base. On the basis of the historical growth of the economy, a short-term population forecast (1988-1993) and a long-term population projection (1988-2050) have been developed for the city (Corporate Resources, 1988). Both are based on an assumed single total fertility rate of 1.56 and three sets of net migration assumptions, low, medium and high.

The short-term forecast has been prepared in accordance with the anticipated slow and moderate economic growth and is therefore subject to review annually based on April Census results prepared by the city and on assessment of current economic developments (Corporate Resources, 1988). Under the medium migration scenario, the city's population is expected to increase on average by 12,240 persons annually over the short-term, 1988 - 1993. This represents a growth rate of 1.823%. According to the low and high scenarios of growth, the city is projected to increase annually by 10,400 and 15,800 persons, respectively. In percentage terms, the low and high growth rates are expected to be 1.535% and 2.294% over the short-term (Table 3-3).

Table 3-3

Short-term Population Forecasts for the City of Calgary (1988-1993 in thousands) as at June, 1988.

Year	Low	Medium	High
1988*	657.0	657.0	657.0
1989	665.3	668.3	670.9
1990	675.3	680.5	686.1
1991	686.0	692.7	702.0
1992	697.2	705.6	718.6
1993	709.0	719.1	735.9

* Estimate as of June 1988, Base year
Source: Corporate Resources- The City of Calgary, 1988.

The economic outlook underlying the short-term population forecast has been modified and extended into the future. Three different scenarios with respect to net migration have been developed for the long-term (1988-2050) (Table 3-4). These long-term population estimates are based on an analysis of the past and anticipated growth of the provincial and local economy and population, together with a review of the historical growth patterns of selected Canadian cities/Census Metropolitan Areas during 1901-1986 (Corporate Resources, 1988).

According to the medium outlook, the city's population is expected to increase annually by an average of 8,940 persons over the long-term and reach one million by about 2016. In percentage terms, this represents an average annual growth rate of 1%. By the turn of the century, the city's population is expected to exceed 800,000. Long-term projections based on the low and high scenarios envisage average annual increases of

Table 3-4

Long-term Population Projections for the City of Calgary, 1988-2050 in thousands.

Year	Low	Medium	High
1988*	657.0	657.0	657.0
1990	675.3	680.5	686.1
2000	783.9	813.2	852.5
2010	874.3	935.2	1007.1
2020	954.5	1047.5	1151.3
2030	1002.7	1128.4	1265.4
2040	1020.9	1187.6	1347.1
2050	1026.1	1212.4	1408.0

* Estimate as of June, 1988

Source: City of Calgary Corporate Resource Department, 1988

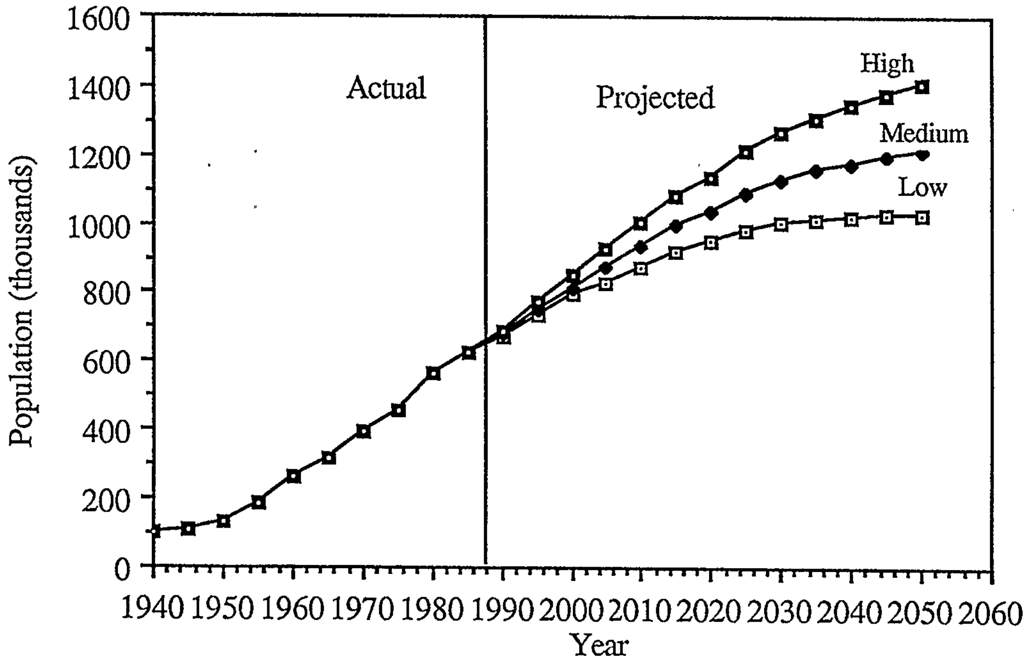

Fig. 3-5. Actual Population and Projections (as at June 1, 1988) for the City of Calgary, 1940-2050.

Source: Corporate Resources, City of Calgary, 1988.

6,030 and 11,990 respectively. These represent growth rates of 0.74% for the low, and 1.24% for the high projections. All these scenarios indicate a tapering-off of the rate at which the city's future population is expected to grow. The growth rate of the medium projection is expected to drop from about 1.8% in the mid-1990s to about 0.4% in the mid-2030s (Fig. 3-5).

In line with the expected growth in population, occupied dwellings (which include apartments, hotels, single-, two-, and multi-family homes) are expected to increase annually by an average of 18,333 over the period 1988-2000. Occupied dwellings are expected to reach over 407,000 by the year 2000 (Table 3-5). This represents an average annual growth rate of 5.3%.

Water Works Division customers (persons with water accounts with the Water Works Division) are expected to be more in line with the anticipated growth in occupied dwellings . The Division's customers are projected to increase by an annual growth rate of 5.4%, reaching over 300,000 by the turn of the century (Fig. 3-6).

Though such projections have been made, it is not likely that they will be attained and they may be overestimated. For instance, in 1988, population, occupied dwellings, and service customers were estimated to be 706,100, 297,700, and 233,031, respectively. The actual 1988 figures were 658,760, 250,174, and 187,069 respectively. These figures represent errors of 17%, 19%, and 25%, respectively. These imply that the projected medium population, occupied dwellings, and water service customers may not be attained. This assertion, however, depends on such factors as net migration and the future economic outlook of the City. However, such projections are significant because they serve as guidelines for the Water Works Division to ensure efficient management of water in the city.

Table 3-5

Occupied Dwellings and Water Works Division Customer Projections, 1988-2000.

Year	Occupied Dwellings	Customers
1988	297,700	233,031
1990	315,800	247,199
1992	334,100	261,523
1994	352,300	275,770
1996	370,800	290,252
1998	389,100	304,577
2000	407,700	319,137

Source: City of Calgary, Corporate Resources, 1988.

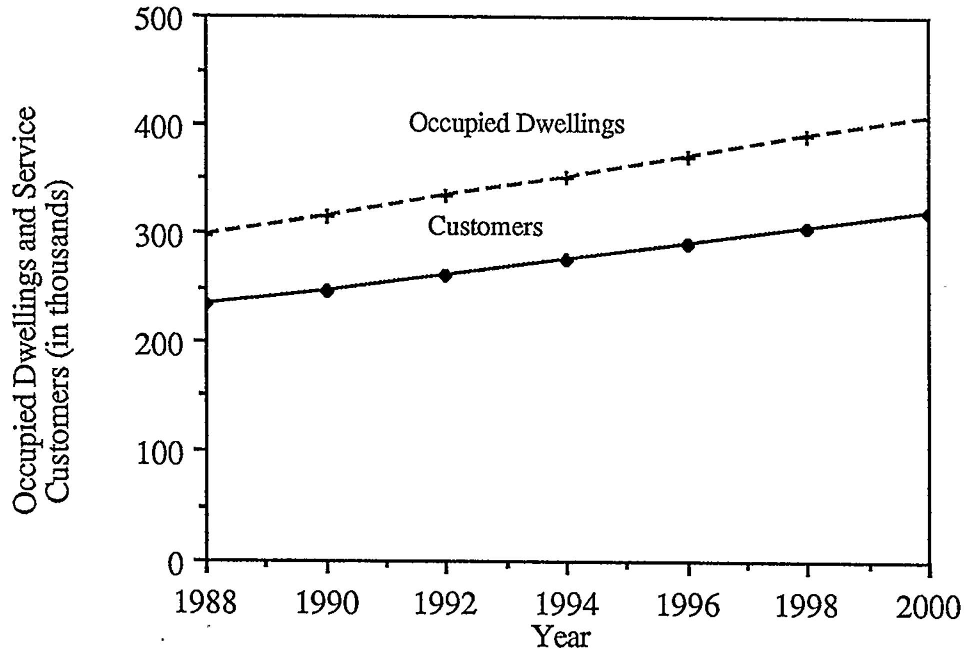

Fig. 3-6. Occupied Dwellings and Water Works Division Customers Projections for the City of Calgary, 1988-2000

Sources: City of Calgary, Corporate Resources, 1988.

3.4 Summary

The City of Calgary draws its surface water from the Bow and Elbow Rivers. These rivers not only provide water to the city but serve other purposes. The rivers also flow to the east of the Province of Alberta, where they are equally important as a source of water supply. Analysis of the streamflow patterns of the Elbow and Bow Rivers at Calgary from 1960-1988 indicates a linear declining trend. Also, a decreasing trend exists in the April through August run-off patterns. Of the two rivers, the Elbow has been experiencing pronounced decreasing trends since 1960. In addition to this, the annual safe-yield (99% reliable flow) of the Elbow river is seen to be less than its water licence. These unfortunate situations are likely to exert pressure on the Bow River, if any operational or supply problems occur.

CHAPTER FOUR

ANALYSIS OF EXISTING WATER CONSUMPTION IN CALGARY.

4.0 Introduction

To determine whether the City of Calgary's Water Works Division water management strategies are achieving the necessary results requires the examination of existing water consumption patterns in the City. Such an examination will provide insights into whether the strategies should be changed or improved upon. It will also provide a guide to determine the water user sector(s) where demand may increase in future. This chapter addresses this issue by examining the existing water consumption patterns in the City from 1962-1989.

The chapter is divided into five sections. The first section examines the relationship between population and water consumption in the city over the past three decades (1962-1989). The measures that have been taken by the City of Calgary's Water Works Division since 1979 to reduce water consumption, after Acres Consulting Services presented its report on Water Conservation to the city, are noted. The second section deals with the relationship between the average, maximum and minimum day water demands since the Acres report. The third section examines the linear trend in the per capita water consumption from 1962 -1989, and accounts for the anomalous behavior in the trend. In the fourth section the major components of water use in the city are identified. This section also considers briefly the metering situation in the city. The fifth section examines water demand projections in the city and considers a balance between water supply and demand in the city. The final section is a summary of the chapter.

4.1 Population growth and water consumption

The City of Calgary has been experiencing rapid population growth since the 1960s. Between 1962 and 1971, the population of the city increased from 270,060 in 1962 to 403,319 in 1971, an increase of about 49% over the ten-year period. The rate of increase, however, dropped to 40% between 1971 and 1980 and dropped further to 19% between 1980 and 1989. Over the past three decades (1962-1989), the city's population increased at about 3.4% per year on average.

Total water consumption increased by 70%, 64%, and 36% over the periods 1962-1971, 1971-1980, and 1980-1989, respectively. On average, total water consumption has been increasing at about 4.1% per year (Fig. 4-1).

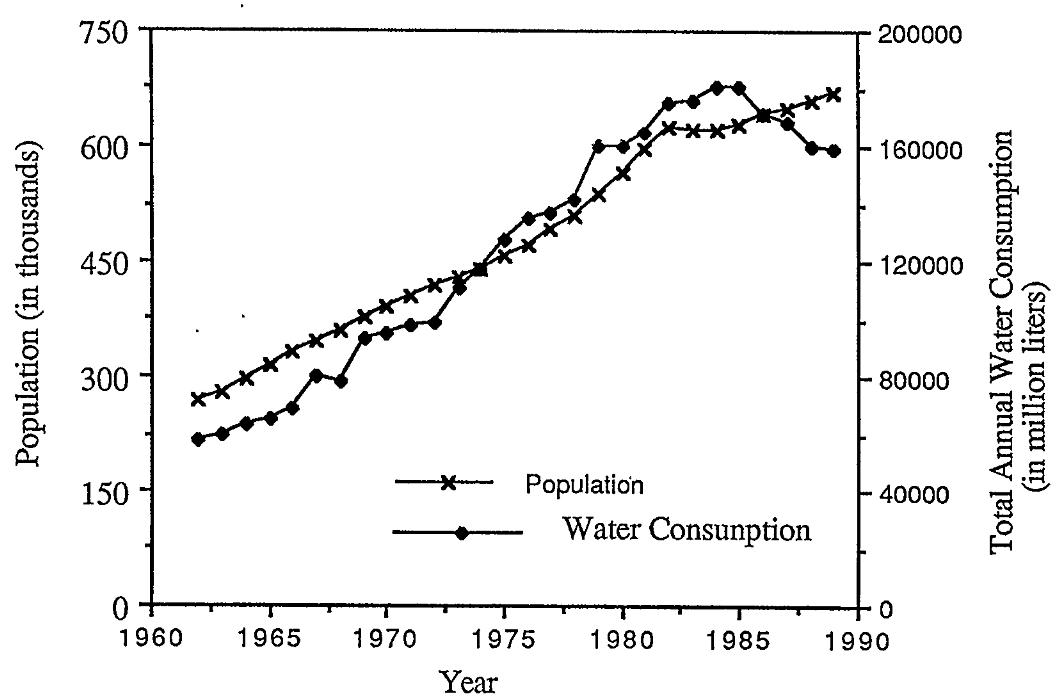

Fig. 4-1. Total Annual Water Consumption and Population for the City of Calgary, 1962-1989

Sources: (a) Corporate Resources Department, City of Calgary, Annual Report, 1990.
(b) Water Works Division, City of Calgary, Annual Services Report, 1990.

Likewise, the average day water consumption (total water consumption divided by the number of days in a year) and the maximum day water consumption (highest consumption day in a year) increased by 3.9% and 3.6% per year, respectively (Table 4-1). Water consumption increased marginally faster than the population, on average, between 1962 and 1989 on the average (Fig. 4-2).

Table 4-1

Yearly Percent Growth in Population, Maximum and Average Day Water Consumption in Calgary, 1965-1989

Year	Population	% Growth	Max. Day	% Growth	Av. Day	% Growth
1962	270060		333		158	
1963	278590	3.10	331	-0.6	164	3.8
1964	297070	6.20	365	10.3	173	5.5
1965	315680	6.60	384	5.2	178	2.9
1966	330575	4.70	372	-3.1	190	6.7
1967	344190	4.10	449	20.7	219	15.2
1968	360760	4.80	490	9.1	213	-2.7
1969	375860	4.20	540	10.2	254	19.2
1970	390680	3.90	534	-11.1	260	2.4
1971	403319	3.20	539	0.9	268	3.1
1972	417780	3.60	518	-3.9	269	0.4
1973	428370	2.50	685	32.2	304	13.0
1974	439770	2.70	630	-8.0	321	5.6
1975	455290	3.50	619	-1.7	348	8.4
1976	469917	3.20	721	16.5	369	6.0
1977	490580	4.40	674	-0.5	375	1.6
1978	509830	3.92	718	6.5	388	3.5
1979	535785	5.09	928	29.2	438	12.9
1980	565825	5.61	755	-18.6	438	0.0
1981	597070	5.52	757	0.3	450	2.7
1982	622725	4.30	824	8.9	478	6.2
1983	620550	-0.35	869	5.5	479	0.2
1984	619700	-0.14	934	7.5	489	2.1
1985	627730	1.30	1037	11.0	487	-0.4
1986	641750	2.23	936	-9.7	461	-5.3
1987	648920	1.12	929	-0.7	455	-1.3
1988	658760	1.52	885	-4.7	447	-1.8
1989	671138	1.88	784	-11.4	423	-3.4

Sources: City of Calgary Corporate Resources Department, 1989 and Long-range Planning Report, Water Works Division, 1989, pp. 1, 8 and 9.

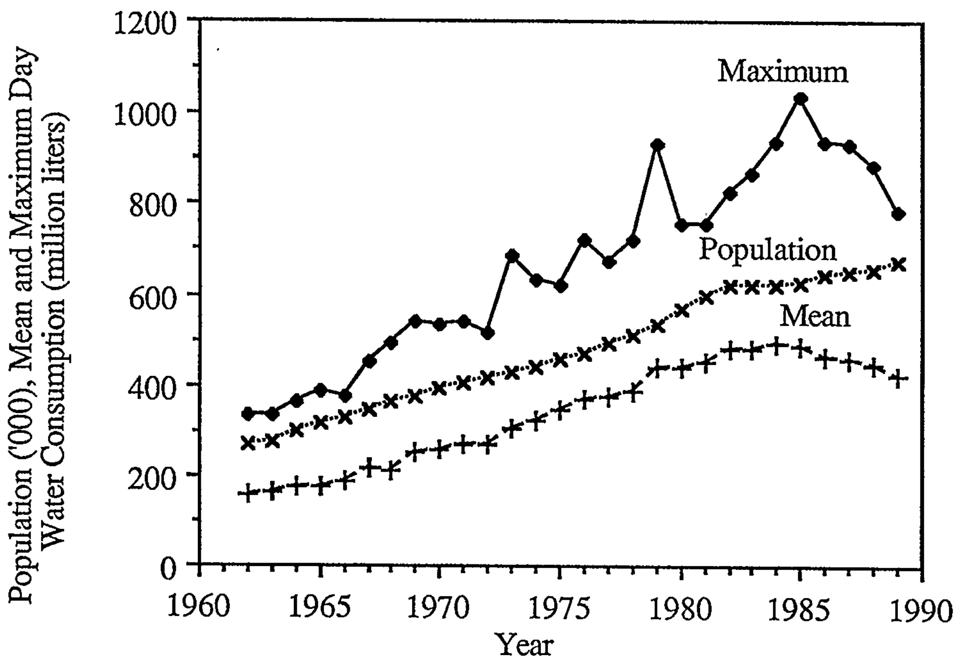

Fig. 4-2 Population, Mean and Maximum Day Water Consumption for the City of Calgary, 1962-1989.

Sources: Corporate Resources, Calgary, 1989 and Water Works Division, Calgary, 1989.

This increasing rate of water use has been attributed to two factors (Harrison, 1989):

1. Flat rate customers who do not "police" their fixtures, from which there is a constant daily loss of water. Single- and two-family residential water users in Calgary have their choice of how they wish to pay for their water, either by a monthly flat rate charge or by having their water metered, and
2. Increasingly higher demands on the water supply system in summer.

These two factors have resulted in the construction of larger and more expensive water treatment, storage and distribution facilities to meet demand (City of Calgary Engineering Department, 1989).

However, from 1985-1989, there has been a declining trend in the total water consumption (Fig. 4-1), average day and the maximum day demands (Fig. 4-2). This may be attributed to the following measures undertaken by the City of Calgary's Water Works

Division since 1979, after Acres Consulting Services Limited had submitted its report on Water Conservation to the City of Calgary (City of Calgary Engineering Department, 1980):

(a) The increase in the water distribution mains replacement program from 8 kilometers per year in 1979 to 26.3 kilometers per year in 1988. From 1979-1988, over 145 kilometers of ductile iron water-mains were replaced with PVC pipes and over 10,000 repairs were carried out (Table 4-2). This program has reduced the number of main breaks per year from as high as 1291 in 1979 to 646 in 1989 (City of Calgary Engineering Department, 1989).

Table 4-2
Water Distribution Mains Replacement and Maintenance from 1979-1989 for the City of Calgary.

Year	Total System (in km)	Replacement (km)	Since 1979 (in km)	Number of Repairs
1979	2542	8.0	8.0	1291
1980	2683	7.5	15.5	1011
1981	2815	6.4	21.9	918
1982	2979	12.4	34.3	1279
1983	2997	14.6	48.9	1105
1984	3024	15.2	64.1	1116
1985	3050	13.8	77.9	1046
1986	3074	18.3	96.2	848
1987	3117	24.0	120.2	811
1988	3165	26.3	146.5	703
1989	N/A	N/A	N/A	646

N/A Data not available.
Source: City of Calgary's Water Works Division, 1990.

(b) The initiation of a leak survey program in 1982. From 1982 through 1989, with the use of electronic detection units, about 408 leaks have been confirmed (Table 4-3). As a result of these leaks, a total of 138 million liters of water were lost between 1982 and 1989. In 1987 alone, about 32 million liters of water were lost per day (Table 4-3). Once these leaks are detected, the distribution mains are repaired.

(c) The implementation of; (i) comprehensive meter testing and replacement program to ensure that all water consumed by metered customers is measured, and (ii) a water conservation awareness program to educate water consumers to reduce water consumption.

It is believed by the City's Water Works Division that the combined effects of these measures may have reduced water consumption after 1985.

Table 4-3.

Confirmed Breaks/Leaks in Water Distribution Mains and Estimated Loss per Day in Million Liters in the City of Calgary, 1982-1989.

Year	1982	1983	1984	1985	1986	1987	1988	1989	Total
Leaks	13	27	19	44	105	86	56	58	408
Loss per day	4.7	5.9	4.7	16.5	26.5	32.0	25.5	22.5	138

Source: Annual Reports, City of Calgary, Engineering Department, 1982-1990.

4.2 Relationship between average, maximum and minimum day demands

Over the years, especially between 1980 and 1984, the average and the minimum day per capita water consumption increased by 1.9 percent and 3.6 percent respectively. On the other hand, the maximum day per capita water consumption increased by 12.9

percent over the same period, reaching a peak in 1985. However, the average, maximum and minimum day consumptions have shown declining trends since 1986 (Table 4-4 and Fig. 4-3).

Over the whole period, 1980-1988, while the mean and the minimum daily demand decreased by 1.4 and 8.4% respectively, the maximum day demand increased by 0.3%. Table 4-4 also shows fluctuations in the peaking factor, which is a ratio of the maximum daily consumption to the mean daily water consumption per capita. This ratio fluctuates to some extent and may depend on maximum summer evaporation as determined by temperature. These ratios show that, to satisfy summer demand, the main supply system must have a capacity equal to approximately 1.9 times the mean daily consumption per capita, on the average. It can be seen from Fig. 4-3 that the highest peaking factor occurred in 1985 (July 10), during which time the maximum day demand reached its peak (1037 million liters).

Table 4-4

Mean, Maximum and Minimum Daily Water Consumption per Capita for the City of Calgary, 1980-1988.

Year	Daily Consumption per Capita			
	Mean	Maximum	Minimum	Peaking Factor
1980	774	1334	583	1.72
1981	754	1268	603	1.68
1982	768	1323	581	1.72
1983	772	1400	579	1.81
1984	789	1507	604	1.91
1985	776	1652	581	2.13
1986	718	1459	567	2.03
1987	701	1432	489	2.04
1988	679	1343	490	1.98

Source: Long Range Planning Report, Water Works Division, 1989.

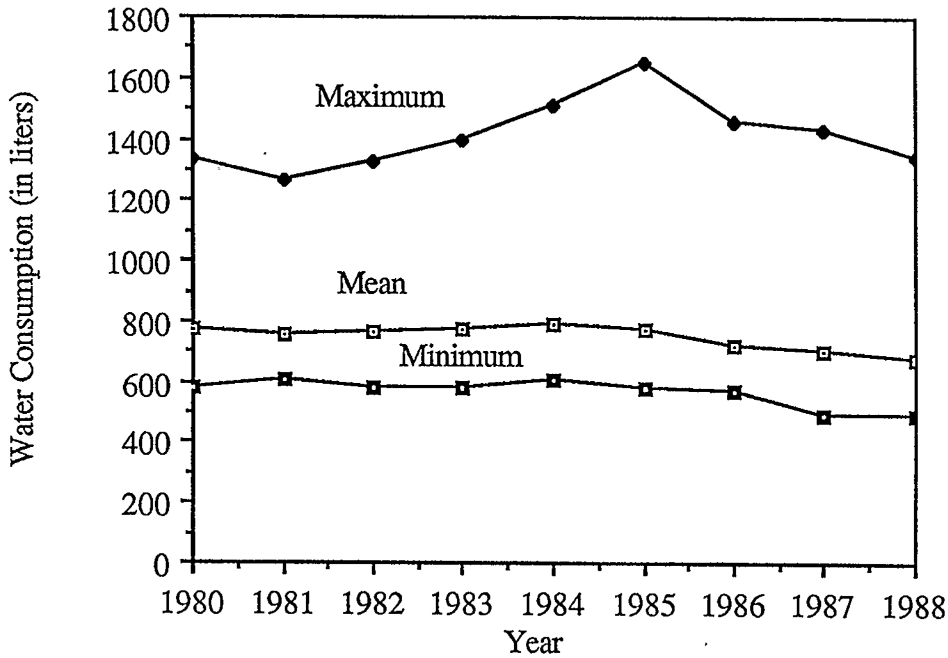

Fig. 4-3. Mean, Maximum and Minimum Water Consumption Per Capita for the City of Calgary, 1980-1988.

Source: Long Range Planning Report, Water Works Division, 1989.

Table 4-5 shows the City of Calgary Water Works Division's estimate of the breakdown of this peak demand. Such a high water use in residential irrigation could be minimized through the imposition of restrictions or moral persuasion, especially in summer.

Table 4-5

Breakdown of Water Consumption by Type on the Maximum Day, July 10, 1985.

Type of Use	Million liters	Percentage
Residential Irrigation	511	49
Other Irrigation	94	9
Residential Indoors	169	16
Commercial	62	6
Industrial	79	8
Leakage	122	12
Other (outside Calgary)	12	1

Source: City of Calgary Engineering Department, 1989. Attachment 2.

4.3 Per capita water consumption

Per capita water consumption has been fluctuating over the period, 1962-1989. An examination of a scatter plot of per capita water consumption reveals two linear trends between 1962 and 1989 (Fig. 4-4); an increasing trend between 1962 and 1984, and a declining trend between 1985 and 1989. Between 1962 and 1966, the per capita water consumption remained fairly constant. This lack of growth in water consumption when population increased 22% was due to the water system reaching capacity prior to the completion of the third stage of the Glenmore Water Treatment Plant in 1966. Added to this were summer water restrictions imposed in 1961, 1962 and 1963. In 1964 and 1965 no increase in consumption took place due to a very wet summer (City of Calgary Engineering Department, 1980). The period 1963 to 1968 was also marked by the transition from cast iron to ductile iron water main installations. However, after 1969, the ductile iron pipes began to corrode, resulting in leakages in the distribution mains. The result of these leakages, among other factors (such as the increase in population) was the increasing trend in water consumption per capita between 1970 and 1979 , with a peak water consumption per capita occuring in 1979 (City of Calgary Engineering Department, 1980) (Fig. 4-4).

It was during this time that the city requested a study be done on water conservation in the city. The study by Acres Consulting Services Limited concluded, among other things, the existence of approximately 28% leakage in the water distribution mains. Since then the City of Calgary's Water Works Division has taken the steps outlined in the previous section. These steps, it is believed, have resulted in the decline in water consumption per capita since 1980 (Fig. 4-4).

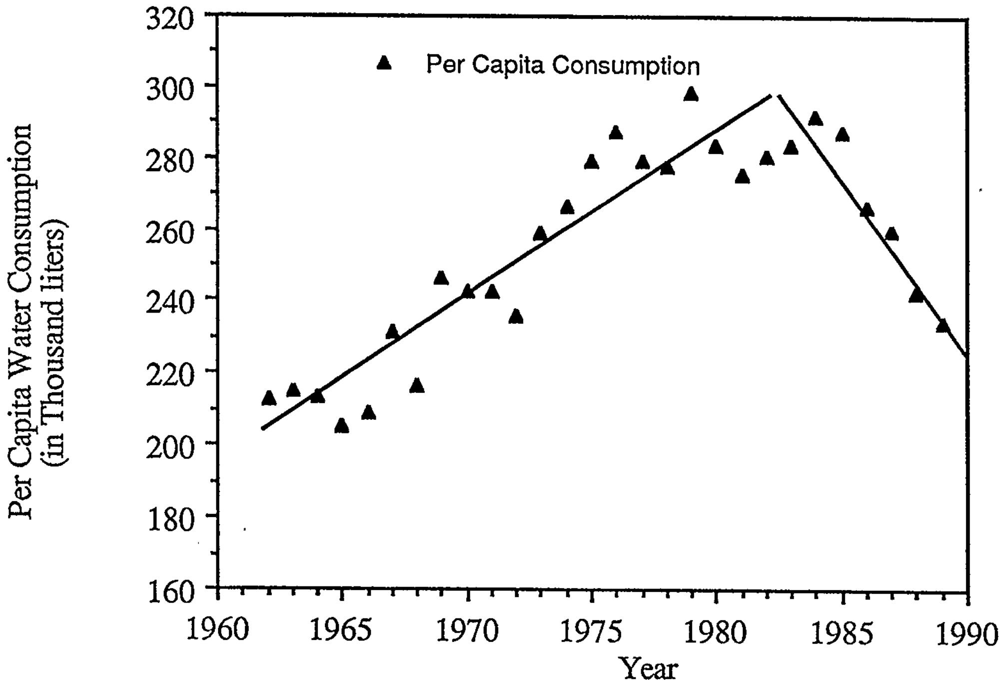

Fig. 4-4. Annual Per Capita Water Consumption for the City of Calgary, 1962-1989

Source: Per Capita Water Consumption calculated by Author from the City of Calgary Water Works Division data sources.

4.4 Components of the total water consumption

The different uses of water in the City of Calgary may conveniently be divided into four general classes: (1) residential use; (2) general service (commercial and industrial use); (3) public use and (4) system leakage.

4.4.1 Residential Use

Residential water use covers all uses of water by households both within and immediately outside the confines of a residence. Thus, it includes requirements for food preparation, laundry, toilet, bathing within a house or apartment, and lawn sprinkling outside. Though the volume of water used varies considerably according to whether the residence is metered or unmetered, overall water consumption by this sector increased steadily, rising from 69,042 million liters in 1979 to 83,626 million liters in 1987 (Fig. 4-

5). However, this dropped to 74,794 million liters in 1989, representing a decrease of 2% from 1987. Residential metered customers account for about six percent of the total water used, on the average, while non-metered residential customers account for over forty percent of the total water use in the City of Calgary (Table 4-6).

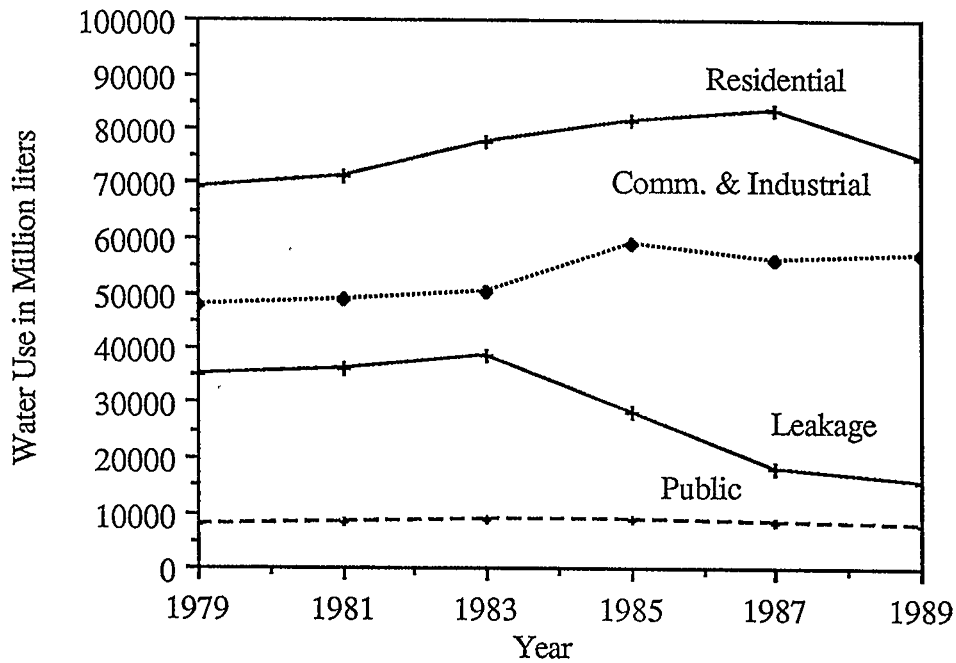

Fig. 4-5. Trends in Municipal Water Use in Calgary, 1979-1989.

Source: Total Services Report of the Water Works Division, City of Calgary, 1979-1989.

4.4.2 General service (commercial and industrial)

Under this heading are included all uses for mechanical, trade and manufacturing purposes. Large users of water for such purposes are office buildings and stores, hotels and restaurants, factories and other industries. The use of water for such purposes increased from 47,619 million liters in 1979 to 56,905 million liters during 1989. Unlike the other components, the percentage share of the total water used by this sector increased from 29.8% in 1979 to 36.7% in 1989 (Table 4-6).

4.4.3 Public Use

This includes water used for public buildings, parks, street cleaning, sewer flushing and the flushing of water mains and fire extinguishment. Though the quantity of water used for such activities increased from 7,990 million liters in 1979 to 8,889 million liters in 1985, it declined to 7,747 million liters in 1989. However, the percentage of the total water consumption by this sector has remained fairly constant (at about 5%) since 1979 (Table 4-6).

4.4.4 System leakage

The chief causes of such waste are poor plumbing and leaky mains. System leakage accounted for 22% of the total water used in the city between 1979 and 1983.

Table 4-6

Components of Municipal Water Use in Million Liters and in Percentages in the City of Calgary, 1979-1989.

Type of Use	1979	1981	1983	1985	1987	1989
Residential Metered	8313	7788	8242	9208	10046	10663
% of Total	5.2	4.7	4.7	5.2	6.0	6.9
Flat-Rate	60729	63278	69109	72431	73580	64131
% of Total	38.0	38.5	39.5	40.7	44.3	41.4
General Service	47619	48964	50288	58808	56003	56905
% of Total	29.8	29.8	28.8	33.1	33.7	36.7
Public Use	7990	8221	8742	8889	8422	7747
% of Total	5.0	5.0	5.0	5.0	5.0	5.0
System Leakage	35158	36174	38467	28445	18285	15494
% of Total	22.0	22.0	22.0	16.0	11.0	10.0

Source: Total Services Report of the Annual Reports of the Water Works Division, City of Calgary, 1979-1989.

However, since 1985 leakage has been drastically reduced from as high as 35,158 million liters in 1979 to 15,494 million liters in 1989 (Fig. 4-4) and now accounts for about ten percent of the total water consumption (Table 4-6). The reduction in system leakage may be attributed to the extensive replacement and maintenance of water distribution mains since 1979.

It must be emphasized that the demand for water for commercial and industrial uses is likely to continue to increase in the future if more communities spring up. However, what is not evident from the data is the proportion used for the various activities within the three major classes (residential, commercial and industrial and the public sector).

4.5 Meters

The City of Calgary is one of the few major cities in Canada without complete water use metering. Most commercial and industrial services are metered throughout the city, while single- and two-family residential consumers may decide to have meters or not (City of Calgary Engineering Department, 1989). This stems from Section 9 of Water Utility By-law 22M82 which reads as follows:

> "No water meter shall be installed or used in a single family or two-family residence as a condition of supplying or continuing to supply water thereto unless the occupant of the residence agrees to the installation of a water meter".

The resulting effect of this by-law is the high percentage of unmetered residential services in the city. There are presently an estimated 175,180 residential services in the city consisting of 136,220 flat rate customers, representing 77.8 percent of the City of Calgary's Water Works Division residential customers. The number and percentage of flat rate and metered customers by type of dwelling is shown in Table 4.7

Table 4.7

Customer Dwelling by Type in the City of Calgary, 1989

Dwelling Type	Flat rate	% of Total Flat Rate	Metered	% of Total Metered	Total
Single Family	116020	85.2	15390	39.5	131410
Two-family	20200	14.8	7290	18.7	27490
Multifamily	N/A		16280	41.8	16280
TOTAL	136220	100	38960	100	175180

Source: City of Calgary Engineering Department: Re-residential Meters, April 3, 1989.

Despite the above by-law, and the fact that the issue of compulsory universal metering was defeated in two referenda (City of Calgary, 1990), the City of Calgary Water Works Division has taken steps to provide meters for some already existing flat rate residences on a voluntary basis. In 1988, for instance, the Water Works Division installed 1,127 meters to existing flat rate customers on their request (City of Calgary Engineering Department, 1989).

What is discouraging is the fact that at a time when the division is adopting every possible means to ensure efficient management of the resource, some residential consumers still convert from metering to flat rate payment structures. Such customers apply for meter conversion under Section 9 of the Water Utility By-law 22m82, since they assume that flat rate customers pay less for the water they consume, no matter the quantity involved (Harrison, personal communication, 1990). In 1988, for instance, three hundred metered customers converted to flat rate. Though opposition to universal metering has been formidable, it is inevitable since senior government officials have indicated they will be less receptive to assisting with financing of future sewage treatment facilities unless metering is used as a method of conserving water (City of Calgary Engineering Department, 1989).

It is estimated that a 27 percent reduction in maximum day demands can be achieved through universal metering. This reduction, it is believed, would reduce the amount of water lost through leaking plumbing fixtures in homes and reduce the amount of water used in residential or unnecessary irrigation, and therefore would reduce the total annual demand. With a reduction in the overall total demand, it is assumed there would be a delay in the requirement for new water treatment facilities by approximately 20 years (City of Calgary Engineering Department, 1989). This is because there will be a correlation between water consumption and charges that will be more equitable and more accurately reflect the "real value" of the resource than does the present flat rate system.

4.6 Water demand forecasting

Water demand forecasting is an integral element in municipal water system planning. However, forecasting water demand is a complex procedure which involves a growing number of legal, economic, environmental, and engineering considerations. For the city of Calgary, based on alternative long-term population projections and past per capita water use, three short-term projections of water demand have been developed (Table 4-8).

A low estimate (A) is based on the implementation of the leak detection program without universal metering. The mid-range projection (B) represents the condition that would occur with the implementation of universal metering. This increase is also tied to the on-going decrease in persons per dwelling of 2.37 in 1989 to 2.30 in 2000. In this sense, if household density does not decline as much as indicated, the projected consumption would increase less. The high projection (C) represents an extreme condition where annual consumption gradually increases to 293,857 million liters by the year 2000 and the population rises according to the high estimate shown in Table 3-4. Projection C is

Table 4-8

Projected Annual Per Capita Water Demand, for the City of Calgary, 1990-2000 in thousand liters.

Year	A	B	C
1990	281	307	353
1992	281	308	354
1994	282	309	357
1996	285	311	361
1998	285	313	364
2000	288	314	359

Source: Adapted form City of Calgary Engineering Department, 1980, p. 72, (with modifications). Actual values in gallons.

provided as an indicator of the potential for rapid increase in demand, since it is unlikely that the higher annual consumption figure would actually be realized within this time frame should the population actually grow at such a high rate. This does not include the phasing-in of leak reduction and 100% metering.

Though these water-use projections may be accurate, they have certain shortcomings in regard to the aggregation of the water data. This is because:

(a) A wide range of pricing structures exists in the city, with predominance of declining block rate or flat rate pricing structures. In addition, the predominance of single family dwellings whose billings depend on lot size and undepreciated assessed value of the dwelling creates high summer-time peak demands.

(b) In addition to consideration of individual variables which affect demand, the differential rates of use of water by residential, industrial and commercial sectors were not assessed before the overall projections were made. The assessment of water use for each sector would provide insight into which sector demand is likely to increase or decrease in the future.

(c) Consumers who draw their water directly from the rivers were not taken into consideration. A typical example is The University of Calgary, which withdraws all its water for lawn sprinkling directly from the Bow River. This water use is not billable. If such customers decide voluntarily or are forced to withdraw water from the city's sources of supply, the projections (made) may be altered.

No matter how accurate these projections may be, since the final aim and results of projecting water demand are closely related to the overall water resources objectives of the Water Works Division, it is recommended that future projections consider the above factors and such other factors as the impact of climate on water use, household composition, price, employment and related issues. This reflects the idea that water demand is most likely to be sensitive to variations in a host of explanatory variables.

4.7 Future demand and supply response

Streamflow decline (Fig. 3-3a and Fig. 3-3b) coupled with moderate economic growth raises questions about the future viability of Calgary's water supply sources. Though the city has determined that water supply from the Bow and Elbow Rivers would be adequate for at least the next twenty years, it is this same city which submitted in 1981 that the volume of diversion from the Elbow River is approaching full capacity of that river under minimum flow conditions (Calgary Regional Planning Commission, 1981). The annual safe yield (99% reliable flow) of the two rivers from which the city receives its water supply has been identified as 655,596 million liters, taking into account the two reservoirs. Thus, the maximum flow is approximately twice the projected demand under scenario C by the year 2000.

Table 3-2 indicates that the annual safe yield of the Elbow River is 106,697 million liters which is less than its water licence. Thus, any further increase in demand must be met by the Bow river. It is with this point in view that the city applied in 1981 for an amendment to its Bow licence to increase the annual withdrawal from 140.6 million liters to 351.5 million liters. This withdrawal, they believe, can be accommodated by the Bearspaw Water Supply Plant.

However, the ability of the Bow and Elbow Rivers to meet the long-term municipal demand (and other demands) in Calgary is dependent not only on the level and timing of future demand for water, and the spatial pattern of that demand, but also on the physical characteristics of the rivers. Declining surface streamflow (in the absence of technological changes, such as river diversion), if continued, implies that in the future all major users will be called upon to reduce water consumption. Another important consideration is the pattern of the city's growth. The area expected to be occupied by urban land uses as of the year 2006 has been identified by the Calgary Regional Planning Commission (1981). Comparison of the 2006 with the 1980 limits of contiguous urban land use suggests a continuation of the past trend that has seen moderate density residential development expand towards the south and northeast. If Calgary were to sustain major growth into the twenty-first century, with moderate density residential development, coupled with the springing up of industries and commercial centers, increased water consumption would be inevitable, and changes in present water use and allocation might be necessary.

4.8 Summary

The City of Calgary has been experiencing rapid population growth since the 1960s. Between 1962 and 1989, the population increased by an average of 3.4% per year. At the same time its water consumption, in terms of the annual total, average and maximum day, increased dramatically outstripping the growth in population (on average), either due to the high percentage of unmetered services or excessive demand in the summer or both. However, since 1986, there has been a decline in the total annual consumption, average and maximum day demands. This is attributed to the water main replacement, leak detection and repair, meter testing and repair, and conservation awareness programs initiated by the City of Calgary's Water Works Division since 1979.

A linear trend of the city's per capita water consumption also showed anomalous behavior, with low and high periods of water consumption. This was the result of changes in technology and system leakage.

With respect to the various classes of water use, residential flat rate customers accounted for over 40% of the total water use in the city. Between 1979 and 1983, system leakage accounted for as high as 22% of the total water use, however, this has been reduced to about 10%. There is a high percentage of unmetered services in the city and it is expected that with universal metering, there will be a further reduction in the total, per capita average and maximum day consumption figures, because there will a correlation between water consumption and charges.

CHAPTER FIVE

METHODOLOGY AND DATA ANALYSIS TECHNIQUE.

5.0 Introduction

One of the objectives of this study is to examine and evaluate the climatic and socioeconomic factors which affect water consumption in the City of Calgary and to determine whether reliable methods of forecasting future water use can be developed. This objective is accomplished through the collection of data on the factors that are postulated to affect water consumption in the City.

The main objective of this chapter, therefore, is to select the variables that will be used in the evaluation and also to select a technique for the analysis. The chapter is divided into three sections. The first section deals with how the variables used in the analysis are selected. In the second section, data sources for the variables selected are given. The final and third section deals with the technique of analysis as well as the criteria for the analysis.

5.1 Variable selection procedure

A variety of factors ranging from climatic to socioeconomic, are well documented in the literature by studies concerned with estimating spatial variation in water consumption. Socioeconomic variables such as population, income, water price, and housing characteristics are postulated to impose long-term changes on water use pattern; while climatic variables such as precipitation and temperature induce short-term seasonal variation in water consumption (Metzner, 1989; Miaou, 1990).

Since Metcalf's (1926) water use study, numerous studies have focussed on estimating the response of water use to both socioeconomic and climatic changes (Larson and Hudson, 1951; Headly, 1963; Howe and Linawear, 1967; Wong, 1972; Young, 1973; Boland, 1979; Carver and Boland, 1980; Cochran and Cotton, 1985; Frankling and

Maidment, 1986; Metzner, 1989, Miaou, 1990). Factors such as temperature, precipitation, income, population, occupied dwellings and price of water have been shown to have measurable effects on per capita water consumption. Headly (1963) noted that a demand relation for per capita water consumption is a function of the price of water and income. Boland (1979) reported that the determinants of water use, measured at the urban level can be shown to be correlated with numerous economic, climatic, and socioeconomic variables. Cochran and Cotton (1985) emphasized that the number of households per thousand population, average price of water per thousand liters, and per capita income are predictive variables for urban water use. Miaou (1990) noted that monthly precipitation and summer precipitation all have potential effects on seasonal water consumption.

This review of the literature led to the selection of the variables which may affect the City of Calgary's water use.

5.2 Data sources

The City of Calgary's Water Works Division made available their records, which included a summary of information on daily water consumption from January, 1982 through December, 1989. Annual water consumption data from 1965 through 1989 were obtained from the same source. Population and total personal income data from 1965 to 1989 were obtained from the City of Calgary Corporate Resources Department.

The measure for per capita income was derived by dividing total personal income by the population of the City of Calgary. Monthly water consumption per capita per day was calculated from the daily water consumption data by taking the average of the sum of all the daily water consumption levels for each month and dividing by the population of the City. Likewise, the annual per capita water consumption was derived by dividing the total annual water consumption by the corresponding year's population. Though water consumption data were available by user class (residential, commercial and industrial and public use), no attempt was made to analyze demand by user class. This is because the data on flat rate customers are merely estimates and are not reliable. Added to this is the fact that the breakdown of data on residential, commercial and industrial, and public water use do not exist.

The recent decline in household size and composition has created an increase in single-family homes. To take this trend into account, the number of households per thousand population was included in the study. This measure was obtained by dividing the number of households in the city for each year by the population of the corresponding year and multiplying the quotient by one thousand.

In the City of Calgary, the pricing system for water for single-, two- and multi-family residential customers varies, depending on whether the residence is metered or not. Non-metered residential customers are on a "flat rate" system. With the exception of the University of Calgary, where all water for drinking purposes is metered and lawn sprinkling water use is non-metered, all commercial and industrial users are metered. Since the rates for residential, commercial and industrial users are not identical, a new measure for price was selected as a surrogate system to reflect the price of water for all the water use classes. The measure designated was the "average price of water per thousand liters". This measure was obtained by dividing total yearly revenue collected by that year's corresponding water consumed (in thousand liters). The quotient was deflated using the Consumer Price Index (100 for 1981), which produced the average price of water per thousand liters in 1981 constant dollars.

Climatic data on total monthly precipitation (in millimeters), mean maximum monthly temperature (in degrees Celsius), the number of precipitation days in each month, and the deviations of mean maximum monthly temperature and precipitation from their historical averages (1951-1980) were obtained from the Atmospheric Environment Service of Environment Canada publications. Data on the above measures were used to determine both the model parameters and the forecasts in Chapter 6.

5.3 Method of analysis

A variety of methods exists for the evaluation of the factors determining water consumption. These include the Coefficient approach, Input-Output approach, Demand Management, Process Modelling and Regression Analysis. The Coefficient approach is a very simple one, which tries to establish a relationship between water consumption and one independent variable such as time or employment. This method, though valid, is limited because it does not establish any causal relationship between water consumption and the independent variable. Input-Output and Demand Management approaches incorporate a comprehensive view of economics and involve the use of econometric techniques. The Process Modelling approach attempts to model water use as an integral part of the production process, and addresses the link between technological change and water use. The limitation of this approach, and the reason it was not used in this thesis, is that each operation, such as a single industrial plant, must be dealt with individually, imposing very high time, labour and budgetary costs (Tate, 1985). The statistical method selected, therefore, is the Stepwise Regression technique.

5.3.1 Stepwise regression procedure

The Stepwise Regression procedure works with the insertion of predictor variables in turn until the regression equation is satisfactory (Draper and Smith, 1981; Pindyck and Rubinfeld, 1981; Shaw and Wheeler, 1985). The order of the insertion is determined by using the partial correlation coefficient as a measure of the importance of variables not yet in the equation.

The basic procedure is as follows:

(a) the correlation coefficients of all the predictor variables with water consumption per capita are calculated. The predictor variable with the largest absolute correlation coefficient value is first chosen to enter the regression equation. This variable is checked for its significance, by examining the entire regression equation using the F-test, and the regression coefficient using the t-statistic.

(b) subsequently, the partial correlation coefficients of all variables not in the regression equation are computed. The variable with the highest partial correlation coefficient is selected and entered into the regression. The overall equation is tested for significance using the F-test.

(c) the contribution which the variable selected in (a) would have made if the variable selected in (b) had been entered first is checked through the use of partial F-value.

(d) the Stepwise method now selects as the next predictor variable to enter, the one most highly partially correlated with water use. Again the overall equation is tested for significance.

The process continues until the regression coefficient of the last entered predictor variable is found to be statistically insignificant.

A linear model expressing the relationship between climatic and socioeconomic variables and water use in the City of Calgary can be expressed in the form:

$$C_t = \beta_o + \sum_{i=1}^{K} \beta_i X_{it} + U_t \qquad (t = 1, 2, \ldots T) \qquad \text{Equation 1}$$

where t is the time index; C_t is per capita water use; X_{it}, $i = 1, 2, \ldots k$, are explanatory or predictor variables; U_t is the residual or error term; and β, $i = 0, 1, \ldots k$ are the model coefficients. Equation 1 is used in examining and evaluating the climatic and socioeconomic factors affecting water use in Calgary.

5.3.2 Criteria for analysis

The variables used in the regression analysis are evaluated using the following criteria:

1. The coefficient of determination (R^2) should be high.
2. All regression coefficients should be statistically different from zero. The Student t statistic, which is derived from the standard error for each of the coefficients is the measurement stick applied in Stepwise Regression Analysis.
3. No serial or autocorrelation should exist among the residuals. Serial correlation among residuals is tested by the Durbin-Watson (DW) statistic.
4. There should be no significant correlation among any of the independent variables (that is, there should be an absence of multicollinearity).
5. Finally, the regression equation should be significant as a whole. This is tested by using the F statistic. The larger the F value, the more likely it is that the explanatory variables do affect the value of the dependent variable.

All these tests are important for "confidence" in the results of the regression analysis and for their perceived utility within and beyond the City.

CHAPTER SIX

DATA ANALYSIS: MODEL ESTIMATION AND FORECASTING.

6.0 Introduction

Modeling urban water use based on climatic and socioeconomic variables plays a key role in urban water resources planning and management, for example, in conservation programs and designing and developing pricing structures. It can also be used for both short- and long-term forecasting and water facility planning. The objective of this chapter is to determine what impacts, if any, climatic and socioeconomic variables have on water use, and to determine if models can be developed to determine the future variability of water use in the City of Calgary.

This chapter is divided into three sections. Firstly, an attempt is made to determine if a relationship exists between water consumption and climatic variables, such as precipitation and temperature. Secondly, the climatic variables that affect the City of Calgary's seasonal (summer) water use are examined and evaluated to determine a model for seasonal water use. A verification of this model is included in this section. Thirdly, with pooled data, an equation that includes both climatic and socioeconomic variables is evaluated to determine if changing long-term patterns of water can be determined.

6.1 Relationship between water consumption and climatic variables.

The relationship between water consumption and climatic variables must be identified because climate has known effects on water use. A number of variables can be used to measure such climatic impacts, varying from evapotranspiration and monthly degree heating days to total monthly precipitation and mean maximum monthly temperature. Total monthly precipitation and mean maximum monthly temperature from May-August in the City of Calgary are used in this analysis because the data are readily available and also the months with high temperature values coincide with periods of high water use.

Figure 6-1 depicts the relationship between precipitation and monthly water consumption per capita per day for the City of Calgary between May-August, 1982-1989. The best fit line through the scatter of points indicates that water consumption per capita decreases with increasing precipitation. The significance of the regression equation, $C_t = 998.63 - 1.86P_t$, (measured by the F-value = 9.6 at the 5% significant level) suggests that there is a negative linear relationship between water consumption and precipitation in the City of Calgary. It was shown earlier that residential irrigation was the dominant use type. This analysis confirms that natural rainfall probably plays a very strong role in curbing irrigation demand.

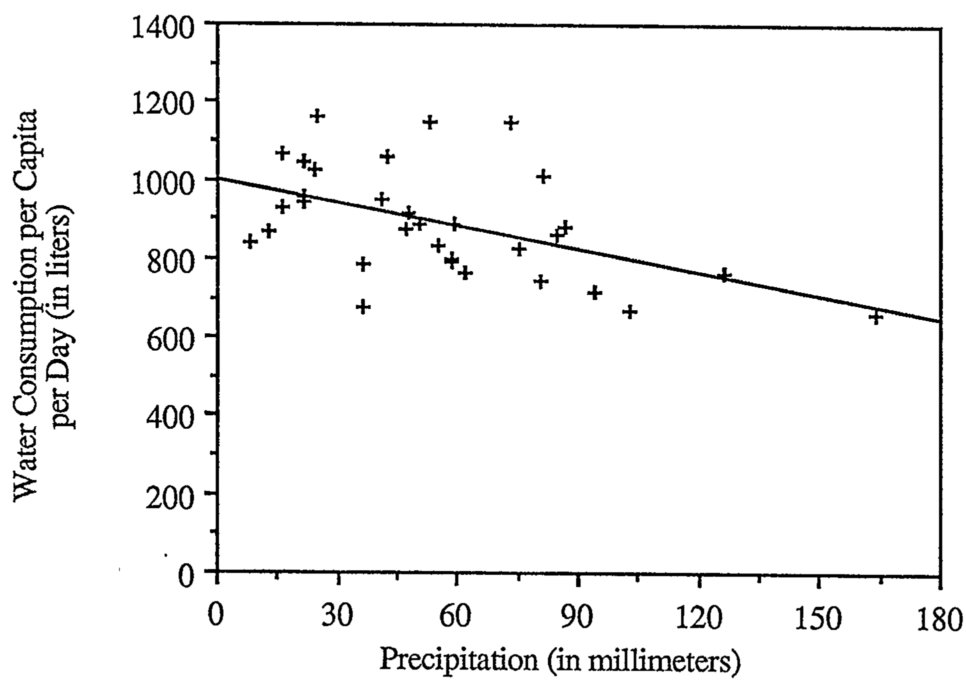

Fig. 6-1. Precipitation and Monthly Water Consumption in Calgary, May-August, 1982-1989.

Linear trend, $C_t = 998.63 - 1.86P_t$, $n = 32$, $R^2 = 0.24$, F-value = 9.6 at $\alpha = 0.05$.

With mean maximum monthly temperature the relationship tends to be different. Figure 6-2 shows a plot of mean maximum monthly temperature and water consumption for the City of Calgary from January, 1982 to December, 1989. A close examination of the scatter of points reveals that the linear trend does not provide a better fit and that two distinct water consumption segments can be discerned. From Fig. 6-2, water consumption seems to be almost constant for temperatures between -12°C and 15°C. Water use increases with increasing temperature when temperature exceeds 15°C, and there appears to be a positive linear relationship between mean maximum temperature and water consumption in the City of Calgary. With mean maximum temperature below 15°C, the correlation coefficient between temperature and water consumption is 0.20. When mean maximum temperature exceeds 15°C, the correlation coefficient jumps to 0.69. The significance of temperatures above 15°C in influencing water consumption is seen in the overall linear equation ($C_t = 199.22 + 31.99T_t$), with F-value of 30.95, which is statistically significant at the 5% error level. This indicates that temperature has a significant role to play in determining water use in the City of Calgary.

The role of temperature is the reverse of that of precipitation. Since evaporation is temperature driven, the higher the temperature the greater the demand for lawn irrigation. Sanitation demand partly driven by increased outdoor activities during warm weather also increases total water use. Figure 6-2 demonstrates also that water consumption during the winter is virtually insensitive to changes in temperature.

Weber (1989) has suggested that one of the ways to overcome distortions caused by linearity assumptions being applied to a monthly time series data is through the use of a seasonal index (a measure used to eliminate variations in time series). The seasonal index identifies in ratio form the monthly water use to a moving monthly average. The results of this method applied to Calgary's water use are presented in Table 6-1.

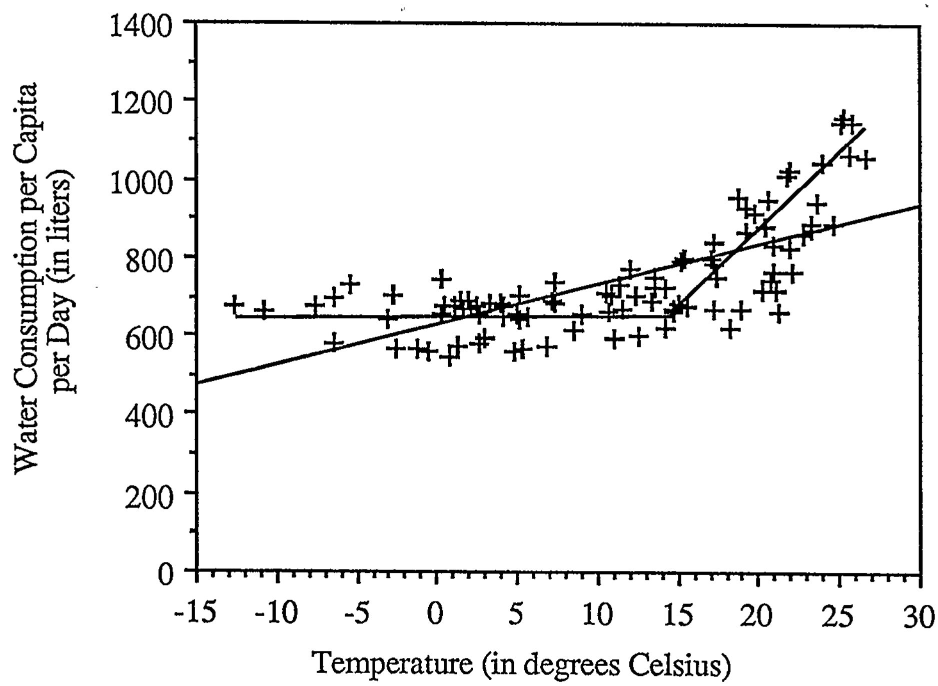

Fig. 6-2. Mean Maximum Monthly Temperature and Water Consumption Calgary, Jan. 1982-Dec. 1989.

Table 6-1

Seasonal Index for Water Use in the City of Calgary

Month	J	F	M	A	M	J	J	A	S	O	N	D
Index	0.86	0.88	0.88	0.94	1.10	1.32	1.24	1.20	0.95	0.91	0.88	0.86

From Table 6-1, in January, for example, water consumption is 0.86 times the average monthly consumption, while consumption in June is 1.32 times the average monthly consumption. This suggests that June water consumption is about 1.5 times January water use. The virtual insensitivity of winter water consumption to changes in temperature is also confirmed by the derived data in Table 6-1. It is not until May, when mean maximum temperature exceeds 15^{o}C (actual value 16^{o}C) does consumption sensitivity to temperature begin. Figure 6-3 shows a plot of Calgary's water use as a function of seasonal index.

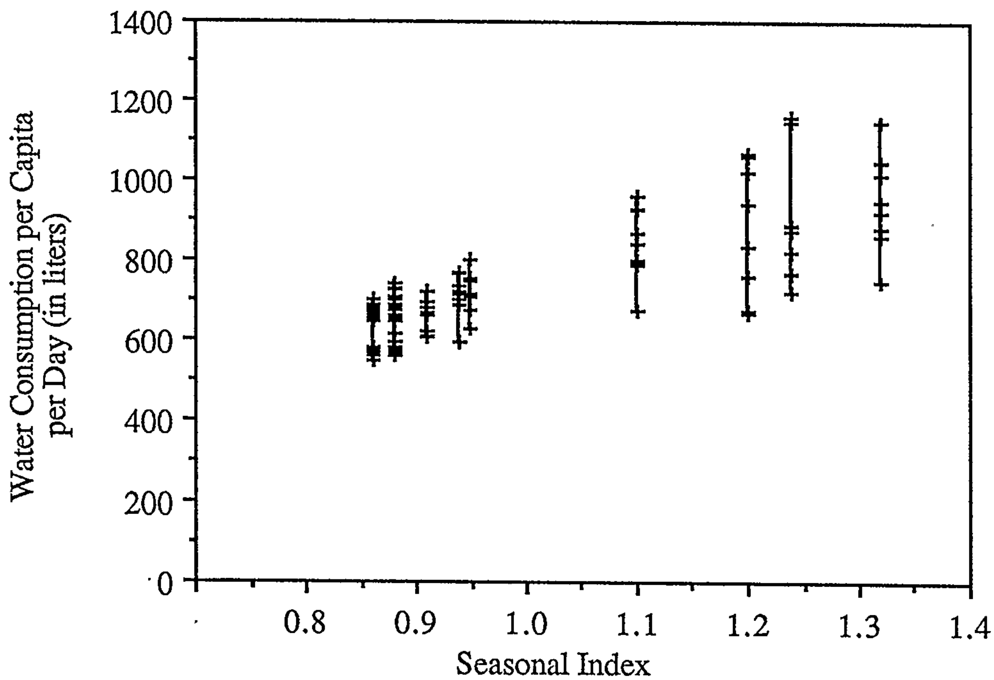

Fig. 6-3. Relationship Between Seasonal Index and Monthly Water Consumption in Calgary, Jan. 1982-Dec. 1989.

The figure shows that for each seasonal index value there is a range of water consumption levels and that this range roughly widens with increasing index values. For example, for an index of 1.24, water consumption varies from as high as 1162 to as low as 700 liters per capita per day. This suggests that either the physical controls on water consumption (temperature and rainfall) are more variable during summer periods or that the range of options open to the consumer is wider during summer. This phenomenon could also result from a combination of both factors. These imply that the seasonal index by itself may not be sufficient for smoothing out all the seasonal variations.

To be able to determine how climatic factors such as temperature and precipitation influence water consumption in Calgary, it is necessary to adopt the two-stage approach as shown in Fig. 6-2 and also to illustrate how consumption is affected by summer precipitation.

6.2 Seasonal water use model from May to August

As a first step to determine a model for seasonal water use in Calgary, a first-order correlation coefficient matrix was computed. This matrix summarized in Table 6-2 identifies the degree of relationship of each variable with each of the other variables. This not only helps in the understanding of what variable(s) drive(s) the dependent variable but also aids in identifying multicollinearity among the independent variables.

Table 6-2

First-order Correlation Coefficient Matrix for Seasonal Water Use for the City of Calgary, May-August, 1982-1985.

	C_t	T_t	P_t	D_t	S_t	R_t
C_t	1.00					
T_t	0.81	1.00				
P_t	-0.21	-0.28	1.00			
D_t	0.49	0.60	-0.56	1.00		
S_t	-0.43	-0.36	0.80	-0.46	1.00	
R_t	-0.30	-0.26	0.82	-0.67	0.48	1.00

Legend

C_t - Monthly water consumption per capita per day from May -August, 1982-1985.
T_t - Mean maximum monthly temperature, May-August, 1982-1985.
P_t - Total monthly precipitation from May-August, 1982-1985.
D_t - Deviation of mean maximum monthly temperature from their historical averages (1951-1980)
S_t - Deviation of total precipitation from their historical averages (1951-1980)
R_t - number of precipitation days in the month.

Table 6-2 shows that total monthly precipitation (P_t) and the number of rainy days in a month (R_t) are highly correlated with each other (0.82) and as such both should not be used directly to explain seasonal water use. The same applies to precipitation and the deviation of precipitation from the normal (0.80). Under the above circumstances Stepwise Regression technique was applied (Equation 1) to determine which of the climatic variables have significant impact on water consumption in Calgary from May to August. The results of the technique applied to Calgary's water use data are provided in Table 6-3.

Table 6-3

Results of the Stepwise Regression Analysis.

Term	Coefficient	t - statistic	significance of t	Beta Weight
Intercept	335.32	2.80	0.01	
T_t	28.79	5.20	0.00	0.83
	Sum Squared	Deg. of freedom	Mean Square	
Caused by Reg.	116874.54	1	116874.54	
About Reg.	84987.21	14	6070.51	
R	0.81			
R^2	0.66			
F-value	27.48			
DW	1.73			

Legend

T_t - Mean maximum monthly temperature, May-August, 1982-1989
R - Correlation coefficient
R^2 - Coefficient of determination
DW - Durbin-Watson statistic

The table identifies the coefficient of the variable included, the t-statistic and its significance, the beta weight of the variable which provides a way in which the effect of the variable in the regression can be assessed, the R and R^2, the F-value and the DW test which measures the degree of serial correlation in the series. The seasonal water use equation then is:

$$C_t = 335.32 + \underset{(5.2)}{28.79T_t} \qquad \text{Equation 2}$$

where C_t represents the monthly water use per capita per day and T_t is the mean maximum monthly temperature.The equation suggests that water use increases with increasing mean maximum monthly temperature. The overall goodness-of-fit of Equation 2, measured by the F-value (27.48), indicates that the probability of rejecting this model is less than 5%.

Before Equation 2 can be finally regarded as both unbiased and the best possible estimate in modeling seasonal water use, it must satisfy the certain preconditions in regression analysis:

(a) the residuals must not be serially correlated, and

(b) a plot of the scatter of the residuals against the predicted water use values should be constant about the zero line. This is a requirement of homoscedasticity (constant variance) (Weisberg, 1980; Draper and Smith, 1981; Pindyck and Rubinfeld, 1981; Shaw and Wheeler, 1985).

The equation with a DW of 1.73 indicates that the residuals are not serially correlated at 5% significant level. This is further shown by a plot of the standardized residuals against the predicted water use values (Fig. 6-4). From Fig. 6-4, the distribution of all the standardized residuals are found to be within -2 and +2 standard deviations, indicating normality and a further proof of 5% level of significance in the results. The results of the analysis indicate that temperature is the only climatic variable (of the five variables employed) that has a significant impact on seasonal water use from May to

August in the City of Calgary. But there is also a hint that summer precipitation is a contributing, if minor, factor. Indeed the negative correlation between precipitation and temperature (Table 6-2) suggests that high summer rainfall years are likely associated with lower seasonal temperature. Thus, the higher the rainfall the lower the temperature (evaporation) and the smaller the consumption. With these reservations in mind, the seasonal forecasting of water demand, based on temperature will be examined.

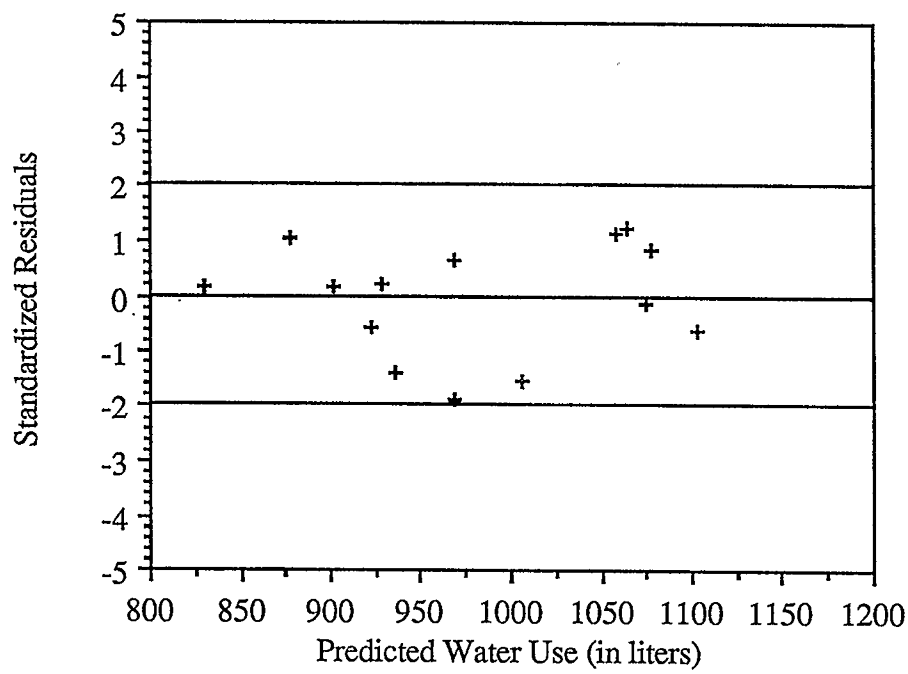

Fig. 6-4. Standardized Residuals versus Predicted Water Use in Calgary, May - August, 1982-1985.

6.2.1 Forecasting Seasonal water use

As a check on the validity of the model developed above, it is used for providing forecasts for water use from May through August, 1986-1989. This will aid in determining whether the model can be trusted for any short-term or long-term forecasting of water use in the City. The period 1986 to 1989 saw a reduction in total water consumption in the City of Calgary as a result of water conservation programs implemented by the City of Calgary's Water Works Division (Chapter 4, Section 4.1)

It should be noted that the actual mean maximum monthly temperature values from May through August, 1986 to 1989 are used in the forecast. The actual mean maximum monthly temperature values are entered in Equation 2 to produce the predicted monthly water consumption per capita. The results of this model verification are presented in Table 6-4.

Table 6-4

Actual and Predicted Water Use for the City of Calgary, May -August, 1986-1989.

Month	Actual Water Use	Actual Temperature	Predicted Water Use	Predicted % Deviation from the Actual
May, 1986	787	17.2	830	-5.5
June, 1986	1013	21.8	962	5.5
July, 1986	870	20.3	920	-5.7
August, 1986	940	23.6	1014	-7.8
May, 1987	869	19.3	890	-2.4
June, 1987	1044	23.9	1023	2.0
July, 1987	902	22.1	972	-7.8
August, 1987	795	18.9	879	-10.6
May, 1988	929	19.3	890	4.2
June, 1988	910	22.7	988	-8.6
July, 1988	905	23.2	1003	-10.6
August, 1988	890	21.2	946	-6.3
May, 1989	676	15.6	784	-15.9
June, 1989	900	20.8	934	-3.8
July, 1989	890	24.7	1046	-17.5
August, 1989	880	21.0	940	-6.8

From Table 6-4, it is apparent that the predicted water use values do not deviate much from the actual usage. Figure 6-5 shows the actual and predicted water consumption per capita from May through August, 1986-1989, and the approximate 95% confidence limits on the forecasts. From Fig. 6-5 the forecasted path is reasonably close to the actual path for May to August, 1986 and May to July, 1987. The gap tends to widen after July 1987 as actual water use tends to decline. The decline in actual water use may be attributed to the cumulative effects of the water conservation measures taken by the Water Works Division since 1980. However, no actual or observed values fall outside the confidence limits for the entire period of the forecast, May-August, 1986-1989. The implication is that Equation 2 could be used to predict future seasonal water use in the City of Calgary with only a 5% chance of error.

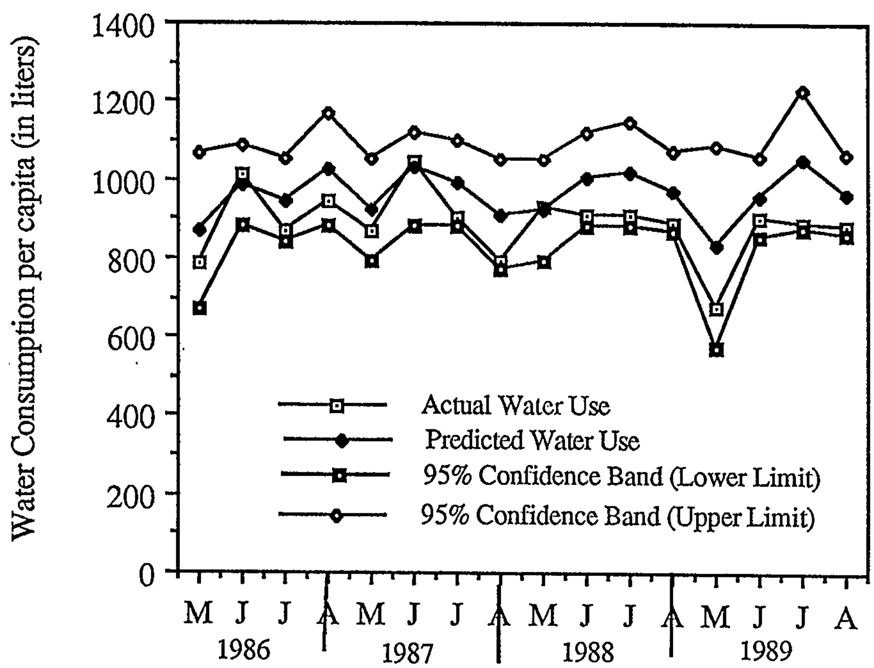

Fig. 6-5. Predicted and Actual Water Use with Aproximate 95% Confidence Bands for May-August, 1986-1989 for Calgary.

6.3 The long-term pattern of water use model.

To determine the long-term pattern of water use model for the City of Calgary, data on the climatic and socioeconomic variables, from 1965 to 1985 were collectively analyzed using Equation 1.

In order to overcome the problem of multicollinearity, the first-order correlation matrix was once again computed. The variables selected for the computation were: yearly water consumption per capita (C_t), number of households per thousand population (H_t), mean maximum summer temperature (T_t), total summer precipitation (R_t), average price of water per thousand liters based on 1981 constant dollars (X_t), per capita income (I_t), population (P_t) and the number of occupied dwellings (D_t) in the City. The coefficient of correlation matrix is given in Table 6-5.

Table 6-5

Results of the First-order Coefficient of Correlation Matrix for Long-term Pattern of Water Use Model for the City of Calgary, 1965-1985.

	C_t	H_t	T_t	X_t	I_t	P_t	D_t	R_t
C_t	1.00							
H_t	0.91	1.00						
T_t	0.21	0.15	1.00					
X_t	0.09	0.42	0.29	1.00				
I_t	0.82	0.96	0.22	0.60	1.00			
P_t	0.85	0.97	0.22	0.51	0.99	1.00		
D_t	0.86	0.98	0.20	0.51	0.99	0.99	1.00	
R_t	-0.26	-0.14	-0.42	-0.11	-0.17	-0.16	-0.16	1.00

As expected four socioeconomic variables were highly correlated with each other: per capita income and number of households per thousand population (0.96), households and population (0.97), households and dwellings (0.98), per capita income and population (0.99), per capita income and dwellings (0.99), and dwellings and population (0.99).

Four socioeconomic variables were highly correlated with per capita water consumption: households (0.91), per capita income (0.82), population (0.85) and dwellings (0.86), all with the expected signs. In contrast, the correlation between per capita water use and the climatic variables were very low, 0.21 for temperature and -0.26 for precipitation, though they all have the expected signs. The positive and negative correlations for mean maximum summer temperature and total summer precipitation respectively, indicate that per capita water use increases with increase in temperature but decreases with increase in precipitation.

The application of Stepwise Regression technique (Equation 1) in the selection of the variables to be included in the model resulted in the selection of three independent variables: households per thousand population, average price of water per thousand liters based on 1981 constant dollars and mean summer maximum temperature. The results of the Stepwise Regression are shown in Table 6-6.

Table 6-6

Results of Stepwise Regression to Determine Long-term Patterns of Water Use Model for the City of Calgary, 1965-1985.

Term	Estimated Coefficient	t-statistic	Significance of t	Beta weight
Intercept	-114500.04	-3.38	0.004	
H_t	972.67	20.68	0.000	0.99
X_t	-819506.99	-7.68	0.000	-0.36
T_t	5638.55	3.49	0.003	0.17
R^2	0.96			
F-value	149.28			
DW	1.88			

Legend

H_t - Number of households per thousand population
X_t - Average price of water per thousand liters in 1981 constant dollars
T_t - Mean maximum summer temperature
R^2 - Coefficient of Determination
DW - Durbin.-Watson statistic

The results show that 96% of the variation in per capita water consumption in the City of Calgary between 1965 and 1985 were explained by variations in households per thousand population, average price and mean maximum summer temperature. Though there was a low correlation between the average price of water and per capita water consumption, the price variable emerged as one of the significant variables in the Stepwise Regression analysis. Therefore, any interpretation of the price variable in the overall equation should be done with caution. Of the two climatic variables selected for the analysis (temperature and precipitation), only temperature appeared to have significant effect on water use. Temperature, therefore, appears to be a consistent explanatory variable in determining water use in both the long-term and the short-term. Table 6-6 also shows that all three independent variables are statistically significant. The long-term pattern of water use model is therefore given as:

$$C_t = 972.67H_t - 819506.99X_t + 5638.55T_t - 114500.04 \qquad \text{Equation 3}$$

where C_t represents the yearly water consumption per capita, H_t is the number of households per thousand population, X_t , the average price of water per thousand liters in 1981 constant dollars and T_t, the mean maximum summer temperature.

The signs of the parameters in the equation imply reasonable correlation between per capita water use and the independent variables. Per capita water use, for example, decreases with increasing price of water and increases with increasing temperature. What is not apparent from Equation 3 is which of the three independent variables has the greatest effect on per capita water use since the units of the independent variables vary from one another. This problem, however, is overcome through the use of the beta weights (which are the standard deviations of each independent variable divided by the standard deviation of the dependent variable multiplied by the partial regression coefficient of the independent variable) shown in Table 6-6. The relative magnitude of the coefficients indicate that the number of households per thousand population is by far the most important predictor of per capita water use in the City of Calgary, followed by average price and temperature. The implication is that, these variables have significant roles to play in long-term patterns of water use in the City.

Finally, the DW value of 1.88 indicates that the residuals are not serially correlated at the 95% confidence level. This indicates that there is only a 5% chance that serial correlation remains in the series.

6.3.1 Long-term pattern of water use forecasting

The estimated equation (Equation 4) for the long-term pattern of water use (1965-1985) is used to generate a forecast over the period 1986-1989 to determine if the equation can be used to determine future long-term changes in water use. The results of the verification procedure are shown in Table 6-7.

Table 6-7

Actual and Predicted Water Use in Calgary, 1986-1989

Year	Water use per Capita	Households /Thousand Population	Average Price of Water	Mean Maximum Summer Temperature	Predicted Water Use per Capita
1986	266,245	379	0.115	20.7	276,616
1987	260,092	379	0.110	21.1	282,969
1988	252,072	380	0.113	21.6	284,302
1989	234,670	381	0.119	20.5	274,156

In Table 6-7, the actual values of mean maximum monthly temperature, number of households per thousand population, and average price of water per thousand liters in 1981 constant dollars from 1986 to 1989 are entered in Equation 3 to obtain the predicted water use values. From Table 6-7, all the predicted water use values are higher than the actual values. The predicted path for the per capita water use and the path per capita water use actually followed are shown in Fig. 6-6 and again enlarged in Fig. 6-7. From Fig. 6-6, in 1986 the forecasted path is close to the actual path but for the last three years, 1987-1989 of the forecast, the gap between the actual path and the forecasted series tend to widen after 1986.

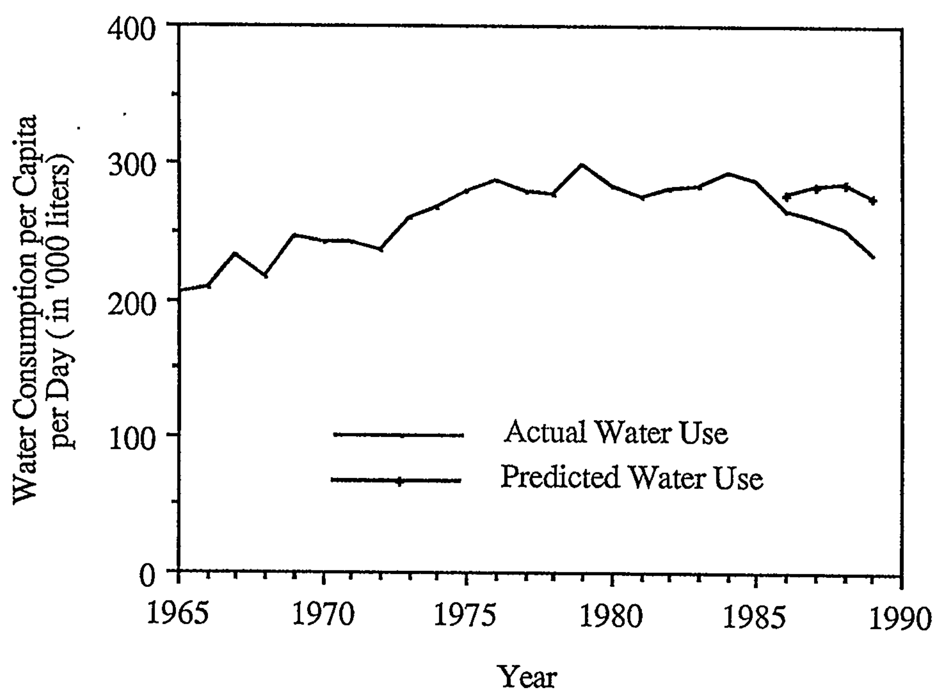

Fig. 6-6. Long-term Actual and Predicted Water Use in Calgary, 1965-1989.

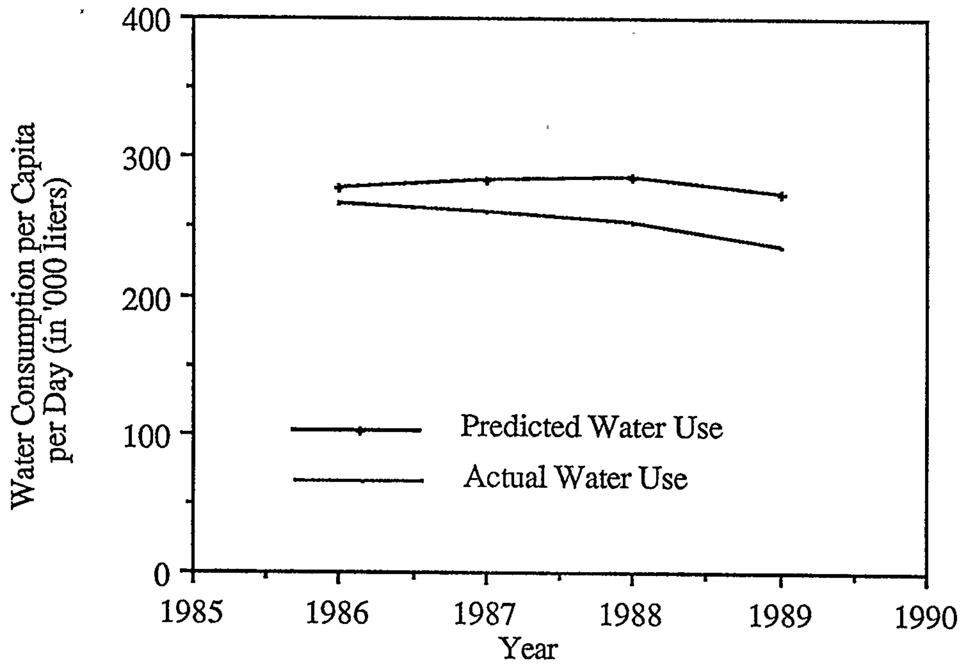

Fig. 6-7. Annual Actual and Predicted per Capita Water Use in Calgary, 1986-1989.

The main weakness of Equation 3 is revealed by a plot of the standardized residuals against predicted per capita water use (Fig. 6-8).The essence of this plot is to determine if the residuals are normally distributed. The scatter of points of the residuals are not evenly distributed around the zero line. This violates the assumption of constant variance in Regression analysis. However, a comparison of the long-term average of per capita water use from 1965-1985 with the actual water use values from 1986-1989 suggest that the 1986 to 1989 actual water use values do not markedly deviate from the long-term average. Table 6-8 shows the actual water use from 1986-1989 and the percentage of the 1986-1989 values to the long-term average (260,902 liters).

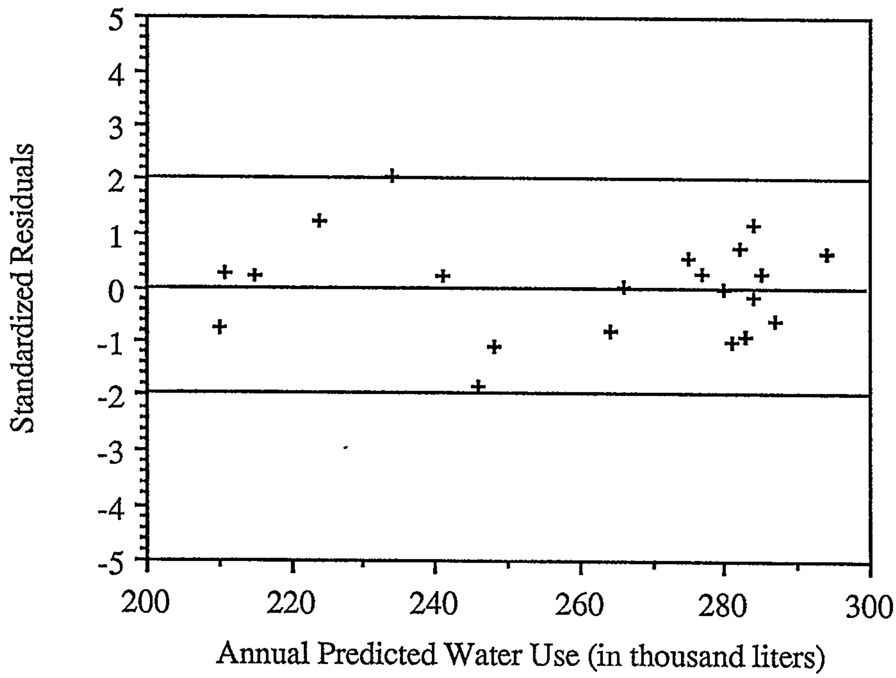

Fig. 6-8. Standardized Residuals Versus Annual Predicted Per Capita Water Use in Calgary, 1965-1985.

Table 6-8

Percentage of Water Used, 1986-1989 in Relation to the Long-term Average, 1965-1985.

Year	Actual Water Used	% of the Average
1986	266,245	102
1987	260,092	99
1988	252,072	97
1989	234,670	90

From Table 6-8, though water use has been declining in relation to the long-term average, the deviation from the long-term average is not so marked. The model describes past water use in the City of Calgary, however, its use in predicting future water consumption should be approached with caution. This is due to the difficulty in predicting certain factors such as temperature. For example, the inclusion of 1990 temperature data would change the coefficients in the model, but not its relative utility.

6.4 Summary

Analysis of water consumption for the City of Calgary from 1982-1989, indicates that climatic variables, such as mean maximum temperature and precipitation have potential impacts on water use. Water use is seen to increase with increasing temperature when temperatures are over 15^0C in the City. The seasonal water use model with temperature as the only climatic variable indicates how important that variable is in determining water use from May -August in the City.

The most notable fact to emerge from the long-term pattern of water use is the importance of the number of households per thousand population in determining water consumption. Again, temperature emerged as one of the significant variables in determining long-term changes in water use. This explains the importance of temperature in determining water use in the City. The significance of the regression coefficients and the entire models (Equations 2 and 3) indicates that both models can be used to forecast water use. However, such forecasting should be done with the necessary precautions.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

7.0 Introduction

This research has focussed on the examination of surface water supply and its demand in the City of Calgary and also developed models to determine future variability of water use in the City of Calgary. The major findings of this study, as well as a discussion of its limitations are summarized in this final chapter. Suggestions for further research are included also.

7.1 Summary and discussion.

There has been a declining trend in the yearly natural streamflow patterns of the Elbow and Bow Rivers since 1960 in the City of Calgary, with the Elbow showing a significant decreasing trend compared to the Bow river. Similar declining trends were noted also in the April through August volumes in the Bow and Elbow Rivers. The average decrease in streamflow estimated for the Elbow and the Bow Rivers in Calgary are 4,150 cu. dams and 19,000 cu. dams per year. These decreasing streamflow patterns are due to changing natural conditions in the southern part of the Province of Alberta. The changes in streamflow patterns of the two rivers are the kinds of effects that would be expected if climatic conditions do not change. However, these averages should be used with caution when determining the variability in the streamflow level of both rivers, since changing climatic conditions can have significant impact on the streamflow levels.

The study also revealed that water use remains fairly steady when temperatures are below 15^{o}C in the City of Calgary. Such temperatures, which usually occur in the winter months indicate that winter water use in Calgary is influenced by societal constraints, and usually involves in-door use. This situation continues until May when water consumption increases with increasing temperatures, especially when temperatures are above 15°C. The implication is that residents of Calgary respond to temperatures above 15°C for increased water use, which may be for yard irrigation, sanitation and other public uses, such as swimming pools and public parks sprinkling.

The significance of past temperature regimes in influencing patterns of water use in the City was again revealed by the forecasting model for seasonal water use. This model is presented as a tool for producing and evaluating future variability in municipal water use and was based on past history of seasonal water use, and a set of climatic variables. Though the final forecasting model contains only one predictor variable, the use of this model to forecast seasonal water use from May to August, 1986-1989 compared favorably with the actual water use values for the period.

In regards to the long-term pattern of water use, three variables were found to have significant impact on per capita water use; the number of households per thousand population, average price of water per thousand liters based on 1981 constant dollars, and mean maximum summer temperature. There are a variety of reasons for expecting the number of households per thousand population to be closely related to per capita water consumption. As number of households increases, more water using appliances, such as dishwater and baths may be installed; also lawns, shrubs and trees may be established around the houses. Finally, large increases in households may give rise to more commercial centres to provide for the needs of the community. It is therefore not surprising that the number of households per thousand population was found to be the major determinant of per capita water use in Calgary. The price of water also emerged as a significant variable in determining long-term changes in patterns of water use. Owing to the general absence of close substitute for water use, the quantity used changes less than proportionately with changes in the price of water. The significance of the price of water may be of particular interest to the city's water managers, because it is the only determinant of water use that is under the direct control of the city's water managers. However, this variable should be interpreted with caution since it is based on 1981 constant dollars.

It is important to note that variables other than the number of households, price and temperature do have a role to play in modeling both seasonal and long-term patterns of water use in the City of Calgary. Equations 2 and 3 explain only 66% and 96% of the variation in per capita water use in the City of Calgary, in summer and in the long term, respectively, therefore other unspecified variables, for example, the number of public parks in the city, may be important in the determination of total water use in the city.

Finally, the use of the models to determine future variability in per capita water use in Calgary should be tested before its application, because of the difficulty in forecasting such variables as temperature.

7.2 Implications

The research has examined the nature of the supply sources of water to the City of Calgary, and estimated models to determine future water use in the City of Calgary. The analysis has revealed that water per se is not in short supply in the city, but that the growing demands for water in the entire Bow River drainage basin may tend to hamper future increased withdrawal licences from the Alberta Environment. Added to this is the fact that, since temperature has significant effect on both summer and long-term patterns of water use, the occurrence of a drought with high temperatures may tend to increase the overall demand for water in the city.

What is required, therefore, is efficient management of the existing sources of supply through demand management (Hanke and de Mare, 1984; Brooks and Peters, 1988; OECD, 1989; Tate, 1989), and should involve measures that are within the direct control of the City of Calgary Water Works Division. Such measures include pricing strategies, regulation, leak detection and allevation and most of all, education, since the modification of demand cannot be achieved without public support.

In regards to pricing, the rates charged for all customers, whether on a flat rate or metered rate should reflect the "real value" of providing the resource; which includes the cost of expansion and maintenance of the water supply system and waste treatment systems. An alternate pricing system would be to charge different rates in the summer months, when water use usually increases. Such pricing systems, it is hoped, would reduce wasteful water consumption and facilitate more rational use of water.

Coupled with the above pricing systems, water use can be regulated, especially in summer, as a way of conserving water. Water use regulations can be applied to both metered and flat rate users. For example, residents can be asked not to water their lawns more than every other day and never between certain hours of the day. It may be true that water users may apply more water than required on their assigned days, but public education and awareness can help to achieve overall demand reduction.

It is hoped that the City of Calgary's Water Works Division would intensify its education on water conservation, initiate new pricing strategies, introduce regulatory measures, and overall inform the public of the nature of the supply sources of water to the city, to ensure rational use of water, since expanding supply systems alone cannot always meet competing demands for water.

7.3 Limitations of the study

Numerous data limitations were apparent in this study. Firstly, the water consumption data were far from perfect, because many single- and two-family residential users have no meters. Despite this the City has lumped water quantities together as an aggregate for residential, commercial and industrial and public uses. As a result the range of average liters use per household or per capita varies significantly. Likewise, "self suppliers", for example the University of Calgary, are not included in this aggregate. Such omissions render the full application of the results of the study to the entire city inappropriate.

A second limitation of the study was in regard to the price data. There is no uniform pricing system for water in the City of Calgary. Depending on the type of service, it is the usual practice for general service and flat rate users to pay a minimum monthly charge, while residential metered rate users pay their charges on a declining block rate structure. Even flat rate users have different rates depending on whether the residence is a single family dwelling or a duplex (duplexes are charged a certain percentage of the "single-family dwelling" rate). In addition, rate determination is further complicated by private fire service equipment and sewer charges. The disparities in the pricing structure make it difficult to draw inferential statements about the price variable.

Finally, there is the problem with the income data. Though data on personal total income were available, some of the values were estimates. Added to this problem is the lack of an income index for the City of Calgary to deflate the per capita income values, in order to remove the effect of inflation.

7.4 Recommendations for further research

The foregoing study has revealed declining trends in the natural streamflow patterns of the Elbow and Bow River in Calgary. However, this rather pronounced reduction in the run-off patterns of both rivers deserves more study by hydrologists and other scientists interested in the Bow River Basin's hydrology before any conclusions are made about the future availability or unavailability of water to meet competing demands, not only in the City of Calgary, but across the province of Alberta and beyond.

Another area which deserves to be looked into is water users who withdraw their water directly from the rivers and who are not included in the city's supply system. The volume of water used by such customers is not known and as such, if such users either voluntarily or are forced to withdraw water from the city, it may have a tremendous effect on the total demand.

The study also revealed declining trends in the total water consumption, per capita consumption, and average and maximum day demands. A critical evaluation of the programs initiated by the Water Works Division after the submission of the Acres Report is recommended. This is to enable the City of Calgary's Water Works Division determine which of the measures has been effective in reducing the overall water consumption.

7.5 Concluding remarks

Two linear models for forecasting seasonal and long-term water use have been developed for the City of Calgary using Stepwise Regression. The models include mean maximum monthly temperature, number of households per thousand population and the average price of water. For the seasonal water use model, temperature is the only important variable, while for the long-term model, the number of households per thousand population is by far the most important variable and temperature is the least. As with any predictive model, predictions are not going to be exact. This is because certain factors such as temperature are hard to predict. The models will be useful tools only if they are regularly updated.

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