uOttawa

L'Université canadienne
Canada's university

FACULTÉ DES ÉTUDES SUPÉRIEURES
ET POSTOCTORALES

uOttawa

L'Université canadienne
Canada's university

FACULTY OF GRADUATE AND
POSDOCTORAL STUDIES

Véronique Sara Paris
AUTEUR DE LA THÈSE / AUTHOR OF THESIS

M.A.Sc. (Civil Engineering)
GRADE / DEGREE

Department of Civil Engineering
FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

Expected Impacts of Climate Change on Water and Wastewater Treatment in the Eastern Ontario Region

TITRE DE LA THÈSE / TITLE OF THESIS

Dr. R. Narbaitz
DIRECTEUR (DIRECTRICE) DE LA THÈSE / THESIS SUPERVISOR

CO-DIRECTEUR (CO-DIRECTRICE) DE LA THÈSE / THESIS CO-SUPERVISOR

EXAMINATEURS (EXAMINATRICES) DE LA THÈSE / THESIS EXAMINERS

Dr. R. Droste

Dr. K. Kennedy

Dr. P. Champagne (absent)

Gary W. Slater
Le Doyen de la Faculté des études supérieures et postdoctorales / Dean of the Faculty of Graduate and Postdoctoral Studies

EXPECTED IMPACTS OF CLIMATE CHANGE ON WATER AND WASTEWATER TREATMENT IN THE EASTERN ONTARIO REGION

By

Véronique Sara Paris

M. A. Sc. Thesis

Submitted to the Faculty of Graduate and Postgraduate Studies

Under the Supervision of Dr. R. M. Narbaitz

In partial fulfillment of the requirements for the degree of M.A. Sc. in Environmental Engineering

Ottawa-Carleton Institute for Environmental Engineering
Department of Civil Engineering
University of Ottawa
Ottawa, ON
Canada, K1S 6N5

Your file Votre référence
ISBN: 978-0-494-25816-3
Our file Notre référence
ISBN: 978-0-494-25816-3

Abstract

Climate change impacts the hydrological cycle. The intensity of extreme precipitation events and droughts is expected to increase, creating stress on the water and wastewater infrastructure. The objective of this study is to assess the potential impacts of climate change on the existing water and wastewater treatment infrastructure in rural Eastern Ontario. In total, 13 municipal WTPs and 28 municipal wastewater treatment systems in the Eastern Ontario region were investigated. These facilities were characterized using existing data, questionnaires, and sites visits. On the basis of this information, potential impacts of climate change were identified. One conclusion of this analysis was the potential need to convert lagoon systems to mechanized WWTPs. Such a conversion would represent a significant financial burden for a small community. Therefore, a cost-estimation methodology was developed, based on the existing CAPDET software.

Dry periods, heavy rain events, heavy spring runoff and increased temperatures are the critical climate change phenomena that are expected to have the greatest impact on the water infrastructure of the study area. It was found that WTPs on the Ottawa River and the St. Lawrence River are not likely to exhibit water shortages, but those using smaller surface water sources are more vulnerable to water scarcity. Furthermore, this vulnerability to water scarcity will be exacerbated by and increase in water demand resulting from higher temperatures and more severe droughts.

Turbidity events typically occur during periods of heavy runoff, and it is expected that climate change will increase the intensity of heavy runoff events. Taste and odor

problems due to algal growth during spring and summer are an existing concern for at least five facilities in the study area. It is expected that this phenomenon will increase as a consequence of increased temperatures, increased evaporation rates and longer dry periods during the spring, summer and fall.

Inflow and infiltration into the sewer system during spring runoff and rain events are typical problems in the study area, resulting in high peak flows at wastewater treatment facilities. Currently, certain WWTPs in the study area use bypass as a method to cope with extreme peak flows. It is expected that climate change will increase the intensity of spring runoff, and the intensity and frequency of rain events. Consequently, it is likely that there will be an increase in the frequency of bypass events, and an increase in the volume of bypassed wastewater.

In lagoon systems, intensified rain events will further swell the normal wastewater flow to several times the dry weather flow, likely causing incomplete treatment of the wastewater particularly at continuous discharge lagoons. During dry periods and warm weather, algal growth in lagoon systems will likely increase. The discharge of effluent containing high quantities of algae will degrade the receiving waters quality.

An increased frequency and intensity of periods of low streamflows will reduce the dilution capacity of receiving waters, particularly in small streams. This increased vulnerability may eventually be reflected in more stringent discharge criteria. A reduction in streamflows could also lead to more extensive algal growth, resulting in more turbidity, more taste and odor problems and possibly algal toxins contaminations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

This project was funded by the Social Sciences and Humanities Research Council (SSHRC), through the Community-University Research Alliance (CURA) which dealt with the adaptation of water resource infrastructure-related institutions to climate change in Eastern Ontario._CURA was a joint effort of the University of Ottawa (UO), the Federation of Canadian Municipalities (FCM), and the St. Lawrence River Institute of Environmental Sciences (SLRIES).

I would like to thank the managing personnel at the Alexandria, Long Sault, Hawkesbury and Glen Walter facilities and the Ontario Clean Water Agency for their kindness in helping me during the survey. Thanks to my colleagues from different fields who shared their experience and knowledge with me. Thanks to my life partner Vladimir and my daughter Nina for giving me the necessary time and space to accomplish this project. And lastly, thanks to my supervisor, Dr Roberto Narbaitz, for his continuous support through this work.

LIST OF VARIABLES AND ACRONYMS

AWWA	American Water Works Association
C of A	Certificate of Approval
$CBOD_5$	Five-day Carbonaceous Biological Oxygen Demand (mg/L)
CURA	Community University Research Alliance
DO	Dissolved Oxygen (mg/L)
DOC	Dissolved Organic Carbon (mg/L)
ENR	Engineering News Record
EOWRMS	Eastern Ontario Water Resources Management Study
ET	Evapotranspiration
GAC	Granular Activated Carbon
GCM	General Circulation Model
IPCC	Intergovernmental Panel on Climate Change
MOE	Ontario Ministry of the Environment
NOM	Natural Organic Matter
NPS	Non Point Source
NTU	Nephelometric Turbidity Units
OCWA	Ontario Clean Water Agency
OCWD	Orange County Water District
PAC	Powdered Activated Carbon
PWQO	Provincial Water Quality Objectives
PTTW	Permit To Take Water
Qw	Water Flowrate
Qww	Wastewater Flowrate
Qww/Qw	Wastewater to Water Flowrates Ratio
SS	Suspended Solids (mg/L)
TOC	Total Organic Carbon (mg/L)
TP	Total Phosphorus (mg/L)
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

CHAPTER 1. INTRODUCTION

There is strong consensus in the international scientific community that the concentration of greenhouse gases in the atmosphere is increasing and that the climate of the earth is changing (IPCC, 2001). Climate change is not only a warming trend; there are associated changes in patterns of precipitation and storms. An important consequence of these changes is increased occurrence and intensity of extreme weather events. These changes have implications for water resources, ecosystems, and human health.

The objective of this study is to examine the implications of climate change on water supply and demand, water treatment, and wastewater treatment in small communities within Eastern Ontario. This study was undertaken as part of a Community University Research Alliance (CURA) study entitled *Institutional adaptation to climate change of water-related infrastructures in Eastern Ontario* (Crabbé and Robin, 2003).

More specifically, the objectives of this study are as follows:

1. Characterization of the water infrastructure of the study area.
2. Investigation of the potential impacts of climate change on the water and wastewater treatment facilities of the study area.
3. Estimation of the cost of replacement of a lagoon wastewater system with a mechanized wastewater treatment plant (WWTP), for a small community.

4. Identification of technical solutions directed at mitigation of potential climate change impacts.

5. Analysis of the response of the water infrastructure system to the impacts of climate change.

Chapter 2 provides a review of the literature on the subjects of climate change; the impacts of climate change on water resources and water infrastructure; and the water infrastructure of the study area. Chapter 3 presents the methodology of the study. The results of the study are presented in Chapter 4. A discussion of these results is provided in Chapter 5. Conclusions and recommendations are presented in Chapter 6 and Chapter 7, respectively.

CHAPTER 2. LITERATURE REVIEW

2.1 Climate change

The source of energy that drives the climate system is solar radiation. Of the total solar radiation, 31% is reflected back into space by clouds, by the atmosphere and by the earth's surface (Kiehl and Trenberth, 1997). The remaining 69% is absorbed by the atmosphere and the earth's surface. An exchange of energy between the earth's surface and the atmosphere maintains, under present conditions, a global mean surface temperature of 14°C (IPCC, 2001).

A stable climate requires a balance between incoming solar radiation and the outgoing radiation emitted by the climate system. Details of this energy balance are shown in Figure 2.1. The left-hand side represents incoming solar radiation, and the right-hand side represents outgoing infrared radiation.

The infrared radiation emitted by the earth's surface, the atmosphere, and the clouds are absorbed by several trace gases present in the atmosphere (the so-called greenhouse gases). In turn, these gases reflect infrared radiation in all directions, including downward to the earth's surface. Thus greenhouse gases trap heat within the atmosphere and warm the air, providing a range of temperatures that allows life to exist on earth. This mechanism is called the natural greenhouse effect.

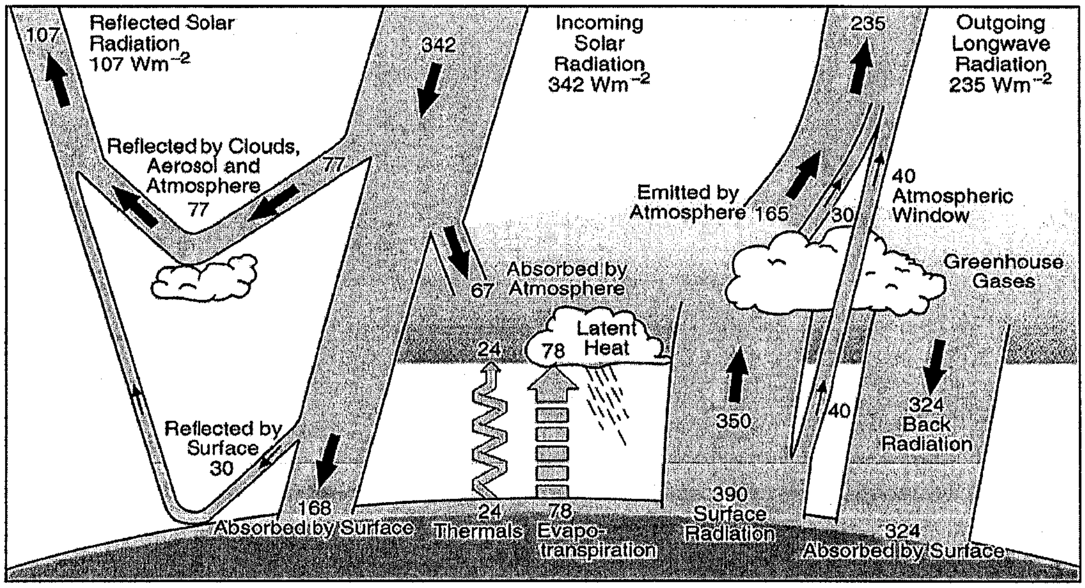


Figure 2.1 **The Earth's annual and global mean energy balance** (Kiehl and Trenberth, 1997)

The infrared radiation emitted by the earth's surface, the atmosphere, and the clouds are absorbed by several trace gases present in the atmosphere (the so-called greenhouse gases). In turn, these gases reflect infrared radiation in all directions, including downward to the earth's surface. Thus greenhouse gases trap heat within the atmosphere and warm the air, providing a range of temperatures that allows life to exist on earth. This mechanism is called the natural greenhouse effect.

The anthropological increase in atmospheric concentrations of greenhouse gases and aerosols affects processes in the climate system. The response of climate to these human-induced changes is complicated by feedback mechanisms, by the strong non-linearity of many processes involved, and by the fact that the various coupled components of the climate system have very different response times to perturbations. Qualitatively, an increase of atmospheric greenhouse gas concentrations leads to an average increase of the temperature of the surface-troposphere system. *Climate Change 2001: The Scientific Basis*, a report published by the Intergovernmental Panel on Climate Change (IPCC, 2001) presents evidence that there has been a mean global atmospheric warming of 0.4 to 0.8°C (at the surface) since the late 19th century. Surface temperature records indicate that the 1990s are likely to have been the warmest decade of the millennium in the Northern hemisphere, with 1995, 1996 and 1998 being the warmest years for instrumentally-recorded history (Crowley, 2000).

There are suggestions that the occurrence of extreme weather events has changed in certain areas during the twentieth century, but a global pattern is not yet apparent (Angel and Isard, 1998). For example, it is likely that in many regions of the world, both in the northern and southern hemispheres, there has been a disproportionate increase in heavy and extreme precipitation rates in areas where the total precipitation has increased (Karl and Knight, 1998). It was also suggested that these changes in patterns would be intensified and that, consequently, more extreme rain events as well as more severe droughts were likely to occur in the future (Fisher et al., 1996). Not all regions of the world are expected to be affected equally: warming is expected to be greater in polar regions and continental interiors (IPCC, 2001).

2.2 Impacts of climate change on hydrology

Murdoch et al. (2000) suggested that with an increase in temperature, the potential evapotranspiration is expected to increase. In some regions, estimated rates of evapotranspiration are predicted to exceed increases in precipitation. In contrast, some regions are predicted to have increased runoff because projected precipitation increases exceed projected increases in evapotranspiration. In regions where evapotranspiration will exceed increases in precipitation, a significant decrease of the mean monthly runoff is expected to result in lower streamflows, declining lake levels, shrinking wetlands, and decreased rates of groundwater recharge. For some regions, the decrease of runoff is expected to occur during all months of the year, possibly accentuated during summer months (Mimikou et al., 2000).

In some regions, warmer winters may produce less snow accumulation and reduce spring runoff, thus exacerbating summer moisture supply problems for regions dependent on this source of moisture (Lewis, 1989). A warming trend on the Canadian prairies may partly explain the shift toward negative snowfall and positive rainfall trends observed within the last 35 years (Akinremi et al., 1999). Lins and Stakhiv (1998) also suggested that an increase in winter streamflow due to rainfall (as opposed to precipitation in the form of snow) and a decrease in the streamflow associated with spring snowmelt would change the annual streamflow pattern. Warmer winters could also shift the timing of peak runoff from late to early spring because of earlier snowmelt (Creese and Robinson, 1996).

In most regions, the actual hydrological pattern is predicted to be accentuated by climate change: wet regions would be wetter and dry regions would suffer from intensified droughts (Pielke and Downton, 2000). Overall, less surface water volume, particularly during the summer, is predicted for North America. The resulting lower levels and flows would reduce water quality and increase pumping and treatment costs for municipal and industrial water users (De Loë and Kreutzwiser, 2000). Lewis (1989) predicted a moderate increase in precipitation combined with higher evapotranspiration for Eastern Canada. The increase in evapotranspiration is expected to be greater than the increase in precipitation, causing decreased runoff for the Eastern Canada region. In areas that consist mostly of agricultural land, decreased runoff could cause an increase of water demand for irrigation (Lewis, 1989).

In the northern region of Canada, the increasing infiltration that develops as the permafrost melts could raise ground-water levels and increase lake depths (Murdoch et al., 2000). Drier conditions would exist in the north-central part of the continent (including the Canadian Prairies), with this dry area increasing and extending westward during the summer. For these regions, not only would precipitation decrease, the probability of extreme dry seasons would also be greater. These regions, which currently experience lower precipitation and greater precipitation variability, could become highly vulnerable to drought (Lewis, 1989).

Climate scenarios for the Great Lakes basin have been generated using the Canadian Climate Centre General Circulation Model (CCC GCM) under $2xCO_2$ conditions. The overland precipitation was predicted to decrease by 2%; evapotranspiration to increase by up to 22%; basin runoff to drop by 32%, and over-lake evaporation to rise by up to 32%. As a consequence, net basin supply could decline 46% (De Loë and Kreutzwiser, 2000). Under these conditions, long-term mean lake levels would decline 0.23 m on Lake Superior, about 1.3 m on Lake Erie and Lake Ontario, and 1.6 m on Lake Michigan and

Lake Huron. With this moisture supply decrease, an increased demand for irrigation could place an even greater burden on the Great Lakes system.

Within the Grand River Basin, a sub-basin of the Great Lakes-St. Lawrence Basin in southwestern Ontario, river flows in the fall and early winter could be lowered by 28-47%, and March and April streamflows could be significantly reduced (Creese and Robinson, 1996).

Flows in the St. Lawrence River are mainly determined by Great Lakes water levels. The flows increase in the spring and summer and decrease in the fall and winter in response to the seasonal rise and fall in lake levels. These flows also increase or decrease from year to year depending on the total annual precipitation. Extended periods of above-average precipitation and low evaporation can cause lake levels to rise and outflows to increase, while severe droughts can result in rapidly falling water levels and decreased outflows (GLIN, 2003). In the case of decreased Great Lakes water levels, as predicted by Mortsh and Quinn (1996) and De Loë and Kreutzwiser (2000), the resulting decreased flows in the St. Lawrence River may allow saline water from the Gulf of St. Lawrence to penetrate farther upstream and alter the freshwater-salt-water balance in the river (Mortsh and Quinn, 1996).

Based on water supply distribution and consumptive indicators, Hurd et al. (1999) suggest that the Eastern Ontario area is not critically vulnerable to climate change, although important impacts are predicted.

2.3 Impacts of decreased streamflows on pollutant concentrations

An expected consequence of decreased streamflow is a corresponding reduction in the capacity of streams to dilute pollutants entering from diffuse or point sources (sewage and industrial waste) (Mimikou et al., 2000). Water quality impairment has already been observed due to loss of stream dilution capacity and low water velocities derived from the reduced streamflows; the impairments include increased biochemical oxygen demand (BOD) and NH_4^+ and decreased dissolved oxygen (DO) (Mimikou et al., 2000). The concentrations of dissolved constituents derived from deeper groundwater flowpaths would also increase as a result of the reduced potential for dilution within the streams (Southam et al., 1999).

On the other hand, under warmer and drier climatic conditions, lower precipitation would decrease the concentrations of surface water constituents typically derived from the flushing of surface and shallow-soil solutions during periods of high runoff (dissolved organic carbon, phosphorus, nitrogen compounds, acidity) and through erosion (phosphorus, particulate organic matter) (Murdoch et al., 2000). Although decreased stream discharge is typically associated with increases in the concentration of chemical constituents (Carmichael et al., 1996), the total export of chemicals could decrease because of reduced runoff. The actual change in concentration in a given lake or stream would therefore depend on the balance between these concentrating and diluting processes.

Decreased scouring in near-stream zones as a result of lower flows would allow vegetation to stabilize riverbanks and further decrease sediment and DOC transport (Murdoch et al., 2000).

Instream DO is typically lowest during periods of low streamflows in climates that experience high seasonal variability. Using the QUAL2E model, which was developed by the United States Environmental Protection Agency (USEPA) and the Environmental Research Laboratory in Athens GA, Carmichael et al. (1996) concluded that the effect of climate change is greatest during low-flow conditions.

In zones where the climate becomes warmer and wetter, there will be greater dilution of point-source pollutants resulting from increased water volume, which would have positive effects on water quality (Cruise et al., 1999). Increased erosion and sediment transport during periods of high runoff could have counterbalancing effects on these water quality improvements (Cruise et al., 1999). A wetter climate would expand the spatial extent of direct runoff to surface waters, thus significantly increasing pollutant loads from point and nonpoint sources that are hydrologically isolated or filtered through aquifers under current flow conditions (Murdoch et al., 2000).

Sediment and nutrient yields in runoff water are highest during storm events (Young et al., 1989). Increased storm-related discharges, with longer dry periods between storms during which pollutants could accumulate would result in increased pollutant concentration in runoff during storm events (Murdoch et al., 2000).

2.4 Impacts of temperature on biological, physical, and chemical properties

Using the A2 and B2 GCMs, the IPCC predicts an increase in annual mean temperature in the range of 3 to 6°C for the Eastern Ontario region (IPCC, 2001) by the end of the 21st century. On one hand, such a temperature increase would theoretically promote the removal of organic matter from a stream, due to an accompanying increase in biological degradation rates which is temperature dependant (Carmichael et al., 1996). On the other hand, an increase in productivity could in turn increase nutrient cycling and accelerate eutrophication (Murdoch et al., 2000).

Other possible impacts of temperature rise include a decrease of streamflow resulting from higher evapotranspiration. This decrease of streamflow will lower both water velocities and turbulence, and thereby reduce stream oxygenation. Higher temperatures also decrease the DO saturation concentrations in streams (Carmichael et al., 1996; Mimikou et al., 2000).

2.4.1 Eutrophication

Eutrophication is the aging process of a lake or river in which algal productivity increases, resulting in wide fluctuations in dissolved oxygen levels. Odum (1971) proposed the following equation to model photosynthesis within a lake:

$$106CO_2 + 16NO_3^- + HPO_4^- + 122H_2O + 18\,H^+ + \text{trace elements and energy} \quad (1)$$
$$\uparrow \ \downarrow$$
$$C_{106}H_{263}O_{110}N_{16}P_1 + 138O_2$$

When this process operates in the forward direction (photosynthesis), CO_2, NO_3, and PO_4 are converted to algal protoplasm and oxygen. When the process operates in the reverse direction (respiration), algal protoplasm is converted back to inorganic nutrients. Equation (1) illustrates how high algal productivity causes wide oxygen fluctuations, as there is a large oxygen production during photosynthesis, and a large oxygen consumption during respiration. Because of this wide fluctuation in oxygen level, as well as high concentrations of algae, the ecosystem associated with a eutrophic body of water usually has a very low diversity of species. In a system undergoing eutrophication, plant forms that have high growth rates usually dominate, eventually these plants die and settle to the sediments, where they require oxygen for stabilization. This further affects the oxygen level within the system.

Eutrophication is a natural process and, depending on existing conditions, may occur over a relatively short period (decades) or a long period (geologic time) (Tchobanoglous and Schroeder, 1987). However, as expressed by Equation (1), the productivity of a system is highly dependent on the input of inorganic nutrients, thus human activities can greatly change the natural rate of the eutrophication process. The addition of high quantities of nutrients to a system will result in eutrophication of the body of water causing algal blooms, followed by decay and depletion of DO. Municipal wastewater, industrial wastes, and runoff from fertilized agricultural lands are all sources of nutrients that stimulate algal growth and accelerate eutrophication. Masters (1998) suggests that phosphorus concentrations of 0.015 mg/L and nitrogen concentrations above 0.3 mg/L are considered to be sufficient to cause algal blooms associated with eutrophication. A system that is tending toward a eutrophic state exhibits severe water quality problems. The presence of large amounts of algae, often blue-green algae or other nuisance types of algae, generally results in very turbid and aesthetically unpleasant water (odor and color) (Waite, 1984).

Many authors have studied the correlations between temperature and algal growth. Dauta (1982) studied the effect of light and temperature on eight algal species from the freshwater phytoplankton in a non-limiting nutrient environment. He found that the optimum algal growth rate is a parabolic function of temperature, with maximums ranging between 20 and 35°C for the different species studied. Figure 2.2 presents the variation of optimal growth as a function of temperature for *Scenedesmus quadricauda*, one of the species studied by Dauta (1982).

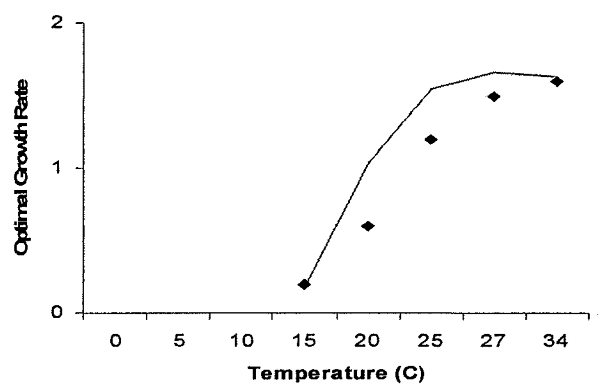


Figure 2.2 Optimal algal growth rate as a function of temperature (*Scenedesmus quadricula*) (Dauta, 1982).

Although these authors generally found a positive correlation between temperature and biological growth, it seems that it is the shift in species following a temperature change that is likely to affect water quality, rather than a temperature-related increase in algal production. Taylor and Dykstra (2002) examined the effects of hot spring water (35-

45°C) on the ecology of a small stream in Nova Scotia, Canada. They found that the hot-spring-induced temperature gradient within the stream had a sharp impact on the communities present at different points downstream of the hot spring. A study performed on a shallow pond in France (Briand et al., 2002) reported greatest proliferation of the blue green algae *Cylindrospermopsis raciborskii* at temperatures between 20.8 and 25.7°C. At these temperatures, *Cylindrospermopsis raciborskii* accounted for more than 99% of the total phytoplankton density. Crabbé and Robin (2003) as well as Waite (1984), reported that in temperate water systems where algal communities are composed of various types of algae, including green algae, blue-green algae and diatoms, temperature increases will result in a shift of the green algae to blue green algae species. In a higher temperature context, blue-green algae will be the only forms present.

2.4.2 Taste and odor

Taste and odor compounds are produced by microscopic organisms such as algae, bacteria, fungi, and, protozoa. The two most common taste and odor compounds are 2-methylisoborneol (MIB) and geosmin, they are known to produce earthy, musty tastes and odors and they can be produced by many types of microorganisms. However, there are many other odor causing compounds, many of which are yet to be identified.

The mechanisms of taste and odor formation as well as the environmental conditions that trigger their production are not well understood. Taste and odor compounds may come from species living in the water, on surfaces, in the bottom sediments or may be produced onshore and washed into the waters during runoff events. Factors influencing taste and odor include temperature, light levels, water clarity, changing nutrient ratios and changing water levels.

Algae are the most frequent cause of taste and odor in surface streams and reservoirs (Quasim et al., 2000). Surface water sources such as lakes, ponds and rivers are likely to experience more severe algae-derived taste and odor problems in a warmer climate with longer and/or more frequent dry spells. A decrease in runoff caused by an increase in evapotranspiration along with longer dry spells will result in smaller river flows. Subsequent increasingly stagnant conditions in some streams would increase the presence of certain types of algae (Hudon, 2000). This may be the case for benthic green algae in the South Nation River (Pick, 2002).

Studies conducted in the Great Lakes (Vogel et al., 1997; Regional Municipality of Niagara, 1993) found that zebra mussels may be associated with taste and odor because they consume planktonic algae, subsequently decreasing the quantities of planktonic algae in the Great Lakes. Decreases in planktonic algae cause increased water clarity. Increases in water clarity allow sunlight to penetrate deeper, stimulating growth of aquatic plants and benthic algae that can be responsible for taste- and odor-creating compounds. Water treatment plants tend to have intakes located in deep water away from shore, so greater algal activity in the vicinity of the intakes may be a factor in the increase of taste and odor episodes. Geosmin and MIB have been widely reported in the St. Lawrence River (NWRI, 2001). In some cases, production of these compounds occurs in situations where high nutrient conditions favor blooms of known odor-producing algae.

However, the recent occurrences in the Great Lakes system come at a time where nutrient levels have reached their lowest levels in decades. In these cases, the sources of these compounds are unknown (algae or bacteria). Pick (2002) suggested that the source could still be benthic green algae. It would seem that although reduced overland flow would imply lower P loadings, the resulting lower flows would increase the shallow surface area and promote benthic algae on rocks.

2.4.3 Cyanobacteria

Animal and human deaths have been associated with toxins produced by cyanobacteria (Jochimsen et al., 1998).

Growth of cyanobacteria ("blue-green algae") may be enhanced by climate change. In times of dry weather, increased retention times and reduce mixing tend to foster the growth of cyanobacteria (Pick, 2002). Cyanobacteria related toxin contaminations could therefore become more frequent in a warmer and drier climate.

Although high nutrient conditions favor cyanobacteria blooms, the occurrence of toxins is not restricted to highly eutrophic water. For example, Brittain et al. (2000) reported the appearance of cyanotoxins in Lake Erie.

2.5 Impacts of climate change on water and wastewater treatment systems

Robinson and Creese (1993) assessed the impact of climate change on water use and wastewater flows in the cities of Cambridge, Kitchener and Waterloo (Ontario, Canada). They found that climate change could lead to a small increase (about 5%) in maximum daily water use by the mid 21st century. They concluded that the water supply system will be more affected on the supply side than on the demand side. Robinson and Creese (1993) also found that, as a result of reduced inflow and infiltration into sanitary sewers due to a lower water table and reduced surface runoff, there will be a reduction in wastewater treated ranging from 5% to 16% for the region's wasteWTP.

Southam et al. (1999) pointed out that target flows designed to maintain minimum acceptable instream water quality would not be consistently met during drier months in affected regions.

2.6 Study area

The study area covers the United Counties of Prescott and Russell, the United Counties of Stormont, Dundas and Glengarry, and part of the City of Ottawa. From a watershed perspective, it includes the South Nation River, the Raisin River and other minor adjacent watersheds, and covers approximately 6,800 km^2. Figure 2.3 shows the study area which is limited to the west by the City of Ottawa, by the Ottawa River to the North and the St. Lawrence River to the South, and by the Hawkesbury-Cornwall axis on the East. It is mostly a rural environment, with approximately 55 percent of its territory dedicated to agriculture. The population within the study area is approximately 186 000 inhabitants. Part of the city of Ottawa and the city of Cornwall are geographically situated in the study area but were not included in the study because they are not representative of small rural systems.

Most of the information presented in the following section was obtained from the Eastern Ontario Water Resources Management Study (EOWRMS) report (CH2M-HILL, 2001), which constituted the baseline for the present study. The Eastern Ontario Water Resources Management Study (EOWRMS) includes an extensive compilation and evaluation of regional water resources and servicing infrastructure information. The United Counties of Prescott and Russell (P&R) and the United Counties of Stormont, Dundas and Glengarry (SD&G) initiated the EOWRMS in recognition of the need to develop a regional water resources information system on a watershed basis.

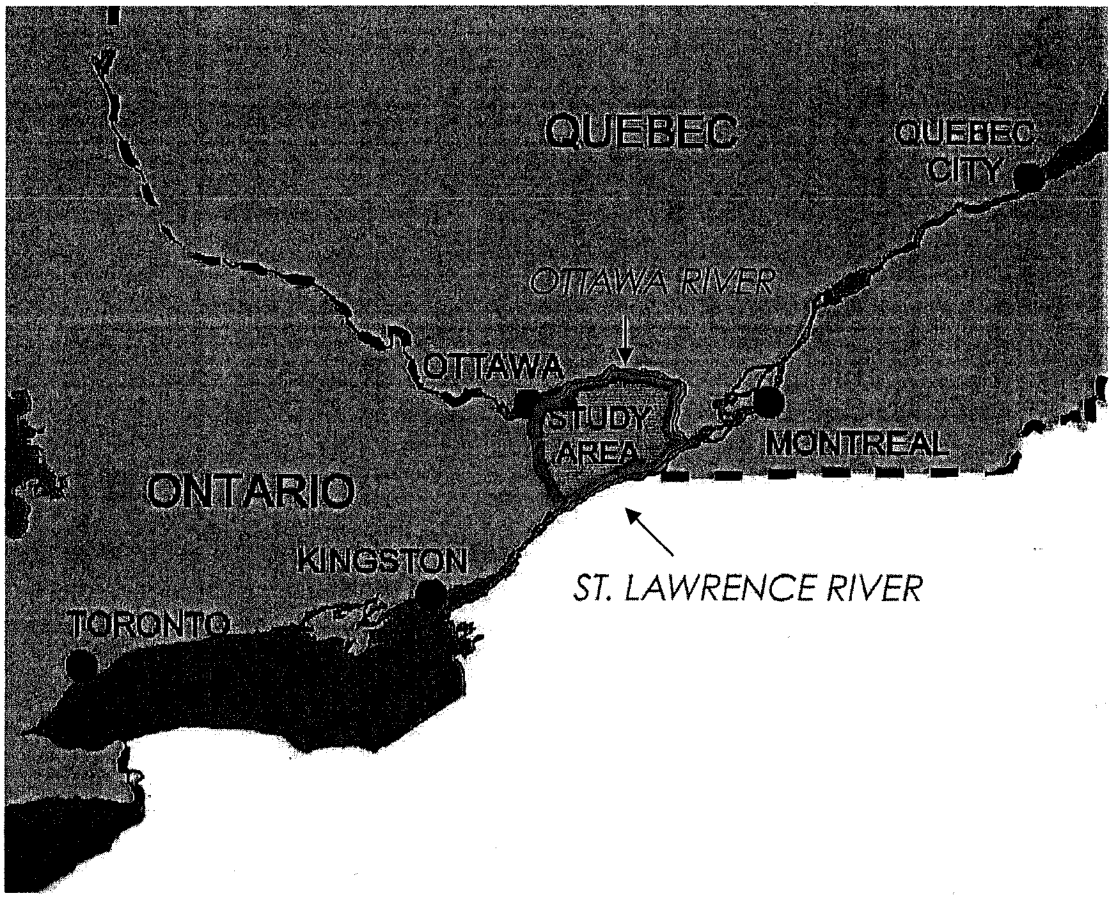


Figure 2.3 **Study area** (after CH2M-HILL, 2001)

2.6.1 Regional water budget

The study area watershed receives on average 930 mm of precipitation annually, of which approximately 420 mm is lost through evaporation and transpiration. The remaining 510 mm of water is partitioned between the surface water drainage network and the groundwater reserves (CH2M-Hill, 2001). The quantity of water available to replenish surface and groundwater resources is quite large, but a major constraint on the quantities is that of water available for use and development relates to the fact that roughly 60% of the precipitation falls in the spring (i.e., March and April), while most of the evapotranspiration occurs in the summer (CH2M-Hill, 2001). Figure 2.4 shows the monthly streamflow variation at a South Nation River gauging station near Plantagenet Springs. These average monthly streamflow values were computed from 1949 to 1998 data and converted to average water depths by dividing the streamflows by the watershed area. The highest streamflow values can be observed during the months of March (82 mm) and April (135 mm). The sequence of monthly peak rainfall versus monthly peak evapotranspiration causes the streamflow regime throughout the study area to have a high seasonal variability.

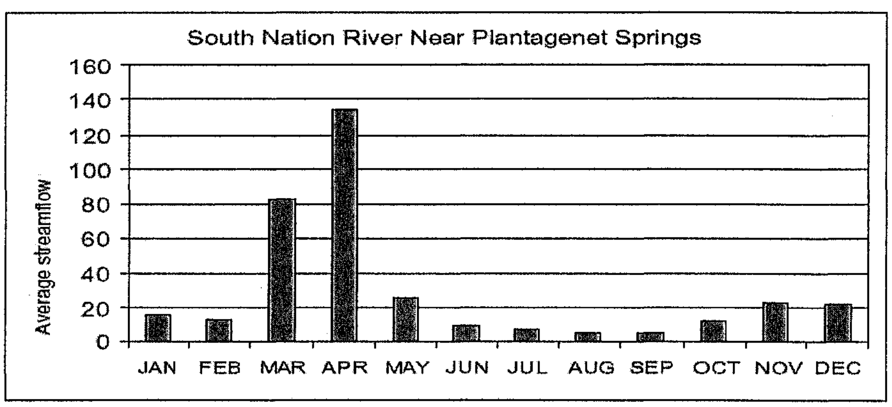


Figure 2.4 Average monthly streamflows at South Nation River near Plantagenet Springs (after CH2M-Hill, 2001)

2.6.2 Surface water quality analysis

Within the study area, nutrient enrichment in the form of high levels of phosphorus is the primary surface water quality issue (CH2M-Hill, 2001). Instream total phosphorus (TP) levels are consistently well above the provincial water quality objective of 30 μg/L total phosphorus (MOE, 1994). In March 2001, the highest TP levels were found in the South Nation River and the Scotch River (a tributary of the South Nation River) with values as high as 500-700 μg/L at St-Isidore (Scotch River) and Casselman (South Nation River). In the Scotch River, TP levels have exceeded 200 μg/L over the past 5 years (CH2M-Hill, 2001; Crabbé and Robin, 2003). Levels of phosphorus decreased at a number of stations within the study area during the ten-year period from 1990-1999, but levels at other sampling stations have increased (CH2M-Hill, 2001).

Ammonia levels in the study area have been generally trending downwards, but there are several cases that demonstrated increasing levels of ammonia, such as the South Nation River near Plantagenet, Casselman, and Chesterville. The increasing levels of ammonia observed at these locations, however, did not exceed the 1.37 mg/L total ammonia Canadian guideline for freshwater aquatic life (Government of Canada, 2002) (CH2M-Hill, 2001).

Within the study area, the data indicate that the following parameters also exceeded guidelines of provincial water quality with the highest regularity: iron, copper, cadmium, mercury, nickel, zinc, and cobalt (MOE, 2003a).

A study by CH2M Gore and Storrie (1992) concluded that the bulk of the nutrient loading in the South Nation River originates from so-called "nonpoint sources" (NPS). Nonpoint sources include a wide range of possible sources such as soil erosion, runoff from agricultural land, leakage from domestic septic systems, livestock access to watercourses, and background levels from watercourse erosion. While the EOWRMS has not included a detailed update of the loading analysis, it states that it is reasonable to presume that since the 1992 analysis, the relative contribution of regulated point discharges has not changed significantly and very likely remains at less than 10 percent of the total nutrient load entering the river system (CH2M-Hill, 2001).

2.6.3 Groundwater supply analysis

The analysis of groundwater capacity for the study area indicates that within each groundwatershed there is potential for additional extraction of groundwater from the contact zone aquifer (upper aquifer) (CH2M-Hill, 2001). It should nevertheless be considered that most of the net available water in the area contributes to the surface water, which suggests that supplies of groundwater recharge at a slow rate, and therefore the capacity for additional extraction of groundwater resources is limited.

2.6.4 Regional water demand

The total annual water demand in the study area is estimated at 34.3 million cubic meters (CH2M-Hill, 2001). Approximately two-thirds (63%) of this demand is met from groundwater. Municipalities supply potable water to approximately 35% of residents, while the remainder relies on private sources, largely from groundwater.

The principal surface water sources in the study area are the Ottawa River, the St. Lawrence River, and the South Nation River.

Municipal water demand includes water for domestic, institutional, commercial and industrial purposes. Together, municipal and private domestic demands account for approximately half of the annual water demand in the study area (29% for municipal and 19% for private domestic). Figure 2.5 presents the water demand distribution for the study area.

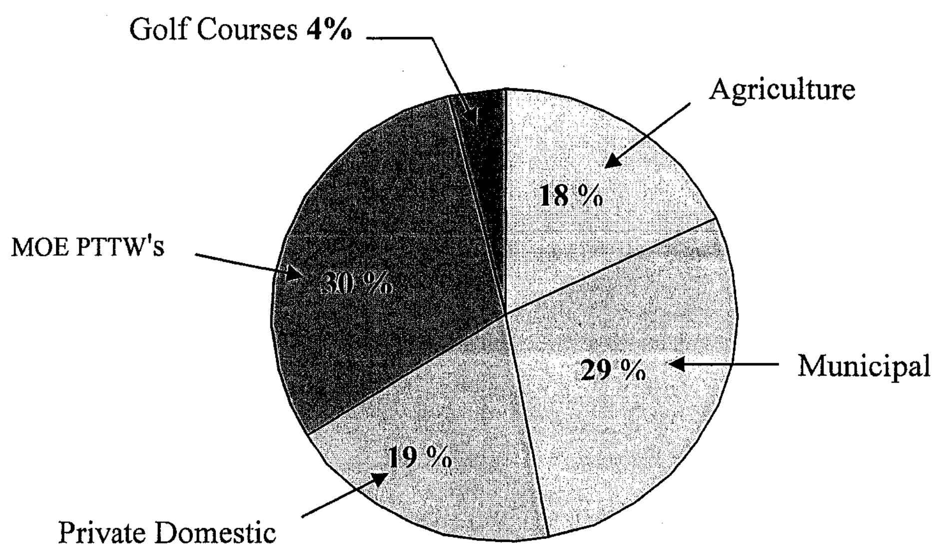


Figure 2.5 Regional water demand distribution (after CH2M-HILL, 2001)

Permits to Take Water (PTTWs) represent 30% of the demand for the study area. PTTWs are required by the Ministry of the Environment for circumstances that involve withdrawing more than 50,000 liters of water per day from watershed or groundwater sources (Government of Ontario, 2003). PTTWs include water withdrawals for commercial, industrial, municipal, public supply, irrigation and recreational use. The portion of the total demand attributed to PTTWs is based on the amount of water that has been allowed to be withdrawn. The quantity of water that is actually removed under the PTTW program is not monitored and not recorded. The actual portion of the global water demand in the area that is attributed to PTTWs is therefore not known with accuracy.

A total of 26 golf courses were identified in the study area, 8 in Prescott & Russell, 9 in Stormont Dundas & Glengarry and 9 in Ottawa. They account for 4% of the water demand plus a portion of the PTTWs.

2.6.5 Municipal water infrastructure

The municipal water supply in the study area is serviced by both groundwater (20 facilities) and surface water (13 facilities). Surface water treatment and groundwater treatment facilities are presented in Tables 2.1 and 2.2, respectively. On average, the surface WTPs service larger communities than groundwater based systems. Communities with groundwater supplies generally have smaller per capita water demand than communities using surface water supplies.

Table 2.1 Surface water treatment plants in the study area (after CH2M-HILL, 2001)

Facility	Total Population Served (1996)	Per Capita Demand (m^3/day)	Avg. Production (m^3/day)	Capacity Utilization
Alexandria	3500	1,013	3546	80%
Alfred-Lefaivre	2200	0,482	977	74%
Casselman	2755	0,380	1047	54%
Glen Walter	450	0,793	357	88%
Hawkesbury	12207	1,071	15000	50%
Ingleside	1550	1,961	3040	57%
Iroquois	1368	1,988	2720	92%
Long Sault	1820	0,883	1607	83%
Morrisburg	2570	0,975	2507	101%
Plantagenet	908	0,482	472	41%
Rockland	8100	0,328	2659	61%
Vankleek Hill	1803	0,316	570	21%
Wendover	824	n/a	n/a	n/a

* Includes demand for industrial usage.

Typical domestic water consumption rates are on the order of 0.4 m^3/d-capita (Brière, 1997). Higher values may arise from industrial usage, leaking distribution systems, irrigation, swimming pool filling, etc. Water demands for Alexandria, Ingleside, Hawkesbury and Iroquois are very high because the WTPs provide water for industries [a textile plant (Alexandria), Kraft Foods (Ingleside), and St. Lawrence Corp. (Iroquois)]. In Glen Walter, watering of lawns and gardens reportedly caused the high per capita demand. In Long Sault and Morrisburg, leakage from the distribution system is likely to be responsible for the high per capita demand, as 70 percent of the distribution system was built during the 1950s (Eamon, 2003).

Table 2.2 Groundwater WTPs in the study area (after CH2M-Hill, 2001)

Facility	Population Served (1996)	Per Capita Demand (m^3/day)	Avg. Production (m^3/day)	Capacity Utilization
Bourget	1437	0,394	283	113%
Cheney	407	0,093	19	18%
Clarence Creek	1002	0,540	270	72%
Hammond	490	0,42	103	158%
St. Pascal Baylon	n/a	n/a	116	53%
Forest Park	537	0,265	142	19%
St. Isidore	766	0,388	298	52%
Embrun	4040	0,325	1311	40%
Russel	3311	0,285	943	71%
L'Orignal	1800	0,361	650	79%
Glen Robertson	120	0,255	31	19%
Lancaster	750	0,267	200	n/a
Chesterville	1553	0,429	666	39%
Winchester	2600	0,673	1750	60%
Chrysler	221	0,79	175	24%
Finch	205	0,88	232	67%
Newington	150	0,46	69	21%
Osnabruck Centre	12	n/a	n/a	n/a
Vars	825	n/a	n/a	n/a
Greely-private sub.	224	n/a	n/a	n/a

2.6.6 Municipal wastewater infrastructure

Figure 2.6 shows the existing wastewater treatment infrastructure distribution for the study area. The major part of the study area's domestic wastewater is treated through private septic systems (septic tanks). Conventional mechanized WWTPs treat 22% of the area's domestic wastewater through 11 WWTPs. The remaining 15% of domestic wastewater is treated through 17 lagoon systems. Tables 2.3 and 2.4 present the area WWTPs and lagoon systems, respectively.

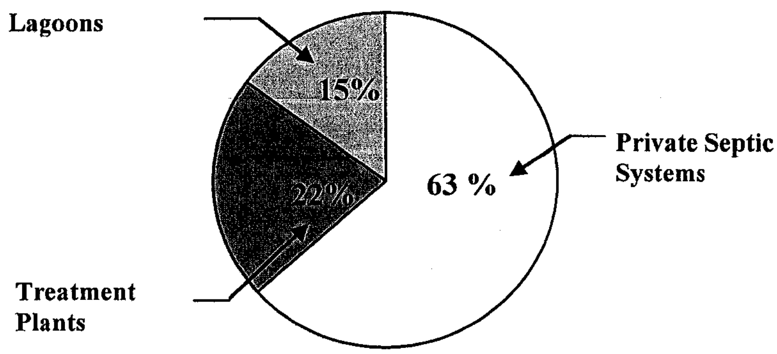


Figure 2.6 Existing infrastructure for domestic wastewater treatment in rural Eastern Ontario (after CH2M-Hill, 2001)

Table 2.3 Wastewater treatment plants in the study area (after CH2M-Hill, 2001)

Facility	Total Population Served	Capacity (m^3/day)	Capacity Utilization
Chute a Blondeau	n/a	109	62%
Limoges	1300	1073	n/a
Glen Walter	600	525	100%
Hawkesbury	10266	12274	79%
Ingleside	1500	4045	84%
Iroquois	1368	n/a	n/a
L'Orignal	1700	955	82%
Rockland	8100	6800	46%
Long Sault	1683	8000	19%
Vankleek Hill	1753	2273	52%
Wendover	984	511	70%

Table 2.4 Lagoon Systems in the Study Area (after CH2M-Hill, 2001)

Facility	Total Population Served	Capacity (m^3/day)	Capacity Utilization
Alexandria	3500	6818	n/a
Alfred	1231	1364	150%
Casselman	2382	1364	79%
Chesterville	1563	1046	62%
Crysler	213	810	24%
Embrun	3717	1798	72%
Green Valley	325	n/a	n/a
Lancaster	750	1000	n/a
Maxville	800	450	n/a
Moose Creek	158	302	39%
Morrisburg	5140	2273	201%
Plantagenet	908	561	119%
Russel	2422	1000	71%
St-Albert	n/a	720	23%
St-Isidore	n/a	655	60%
Williamsburg	350	1227	20%
Winchester	2600	1725	83%

The Alfred, Morrisburg, and Plantagenet lagoons presented in Table 2.4 are currently operating well over design capacity.

CHAPTER 3. METHODOLOGY

The methodology of this study consisted of the following steps:

- Characterization of each water infrastructure facility in the study area;
- Analysis of potential problems related to the impact of climate change on the water infrastructure of the study area;
- Application of a cost estimation model to the construction of small scale mechanized wastewater treatment facilities;

3.1 Characterization of the water infrastructure in the study area

3.1.1 Review of existing data

The final report of the Eastern Ontario Water Resources Management Study (EOWRMS) (CH2M-HILL, 2001) provided background information on land use, population, water usage and water infrastructure. With this information, it was possible to structure a data collection process on the region's water and wastewater treatment facilities.

Data pertaining to facilities flows, effluent quality, details of processes and equipment, and nature of collection systems were not available, or incomplete, within the EOWRMS report. The Ontario Clean Water Agency (OCWA) provided information on wastewater treatment facilities flows and effluent quality in the form of a database containing data on industrial and municipal wastewater treatment facilities in the province of Ontario (OCWA, 1998).

Waste Water Discharge Reports published by the Ontario Ministry of the Environment (MOE, 2003c) provided information on wastewater treatment facilities compliance with government policies and guidelines. The MOE also provided information on the operating authorities of the facilities; this information played a key role in contacting utilities personnel for additional investigation. The Drinking Water Surveillance Program reports (MOE, 2003a) provided information on water treatment facilities.

Prior to 1993, the Ontario Ministry of Environment owned and operated water and wastewater treatment systems in several hundreds of small communities, including many within the study region. Since 1993, the provincial government no longer administrates these systems. The municipalities are responsible for hiring a specialized company to manage their facilities, or to manage them with their own personnel. The OCWA, a crown corporation created by the Ministry of Environment and Energy to manage the water and sewage activities, operates 18 of the study area's facilities. CANEAU Water and Sewage Operations Inc. operates 8 of the study area's facilities, the municipalities themselves operate the remaining 16. Appendix A presents information on the water and sewage infrastructure management in the United Counties of Stormont, Dundas, Glengarry, and Prescott and Russel (Burhoe, 2003). The distribution of operating authorities represented a challenge during the data gathering.

The data available from the previously mentioned agencies and organizations allowed a better understanding of the facilities operations and conditions, but did not give any indications of possible climate change impacts on water treatment infrastructure. At this point in the project, a field survey was planned and organized in order to accomplish the study's objectives.

3.1.2 Facility visits

A series of facility visits were undertaken to interview operating and managing personnel and obtain detailed data for daily flows, effluent quality, and raw water quality, if available. During the facility visits, a tour was performed, allowing for gathering of supplementary comments and observations.

Three survey questionnaires were developed in order to frame the interviews. One questionnaire was developed for each of the following types of treatment: drinking water treatment (of surface waters), mechanized wastewater treatment, and lagoon systems. The three questionnaires are presented in Appendix B.

3.2 Analysis of potential problems

Literature concerning actual impacts of precipitation pattern changes or temperature changes on water and wastewater treatment infrastructure is very scarce. Based on the information about climate change impacts on hydrology, potential problems were identified for each type of treatment facilities (WTPs, wastewater treatment with mechanized plants, and wastewater treatment with lagoon systems).

Operating data were analyzed with respect to temporal precipitation patterns for those facilities and time periods for which data was available. Parameters reflecting potential climate change induced problems as previously identified (increased water demand, increased turbidity, increased algal blooms, increased infiltration etc.) were correlated to different precipitation patterns.

3.3 Application of a cost estimation model (CAPDET)

Because wastewater treatment through lagoon systems is dependant on naturally occurring processes, which in turn are directly affected by factors which humans have little control on such as temperature, sunlight and precipitations, an early conclusion of the present work is that the type of facility which will be most sensitive to climate change induced problems is the lagoon system. Consequently, it can be expected that there will be incentive to convert from lagoon systems to mechanized wastewater treatment facilities. As lagoon systems typically serve small communities, they would be replaced by small scale mechanized WWTPs which will be relatively expensive on per capita basis. Therefore the cost of these replacements will be an important issue for such communities. In order to address this issue, the CAPDET cost estimation model was used to estimate the capital cost of small scale mechanized treatment plants in the study area. This provides both general capital cost estimates for such facilities and a methodology that could be applied to specific cases.

3.4 Discussion of initial methodology (past analogues method)

An initial methodology utilizing the ''past analogues method'' was attempted and abandoned because the infrastructure system has evolved over time such that it is not possible to apply past analogues to the present system. This is discussed further in the present section.

The ''past analogues method'' was the original methodology considered for this study. This methodology, as applied to this study, was to have consisted of the following steps:

- Identification of potential problems related to the impact of climate change on the water infrastructure of the study area;

- Development of specific climate scenarios;
- Association of specific years from the past 100 years with each specific climate scenario;
- Collection of data for the water infrastructure facilities of the study area for the climate scenario years;
- Analysis of the response of the water infrastructure in each of the climate scenario years;
- Extrapolation of the analysis of the response to increased frequency of the climate scenarios.

The past analogues method (which analyzes historical data to study the natural variability of the climate) was applied to the study area by a Community-University Research Alliance team (Crabbé and Robin, 2003). Seven scenarios were built using historical data for precipitation and temperature. Years that best represent a base case year and six critical climatic scenarios were selected from the last 100 years. The six critical climatic scenarios were representative of critical conditions for the multidisciplinary CURA team (hydrogeology, biology, agriculture and engineering).

For the present study, an attempt was made to apply the past analogues methodology. Three of the seven scenarios developed by the CURA team were identified as the critical scenarios with respect to water and wastewater infrastructure in the region: a warm winter followed by a dry spring and a dry summer, a warm and wet spring following a wet winter, and a warm and dry summer with extreme precipitation events. The years associated with these scenarios are 1966, 1973 and 1975, respectively. The years associated with the base case scenario are 1941 and 1909.

However, all of the facilities in the study area, with the exception of certain lagoon systems, were either substantially upgraded or built during the past 20 years. Consequently, the past analogues method could not be applied to the current study, because the present system is substantially different from the system that existed at the time of the scenario years.

Furthermore, efforts to locate data for the systems that existed in 1941, 1966, 1973 and 1975 proved unsuccessful. The only data that were located consisted of an MOE wastewater discharge report from 1975. However, very little data on operation were presented in this discharge report. The data available in the discharge report included capacity of the facility, population served, discharge criteria and bi-annual discharge data.

CHAPTER 4. RESULTS

4.1 Characterization of the water infrastructure in the study area

The study area and the facilities on its territory are presented in Figure 4.1.

4.1.1 Water Treatment Plants

For the purpose of this study, as a result of limited resources, only WTPs supplied by surface water will be analyzed. The usual treatment train applied to raw water before it can be distributed for drinking purposes is: addition of chemical (alum or alum derivates) for coagulation, flocculation, sedimentation, filtration, and disinfection. Depending on the source water characteristics, other treatment objectives may be accomplished by adding different treatment units. For taste and odor removal, for example, a granular activated carbon (GAC) unit may be added to the treatment train.

Small sized plants routinely monitor coliforms, turbidity, pH, alkalinity and chlorine residuals. In general these analyses are performed daily, but some smaller facilities might only take samples every two or three days. Local conditions may require that other parameters such as color and hardness may also be monitored regularly. A complete water analysis, including all regulated toxic chemicals, is conducted every three months (MOE, 2003a). Flows and chemical dosages are also usually recorded on a daily basis. More sophisticated plants (usually servicing larger populations), such as the Hawkesbury

WTP, monitor chemical dosages and water characteristics at different stages of the treatment.

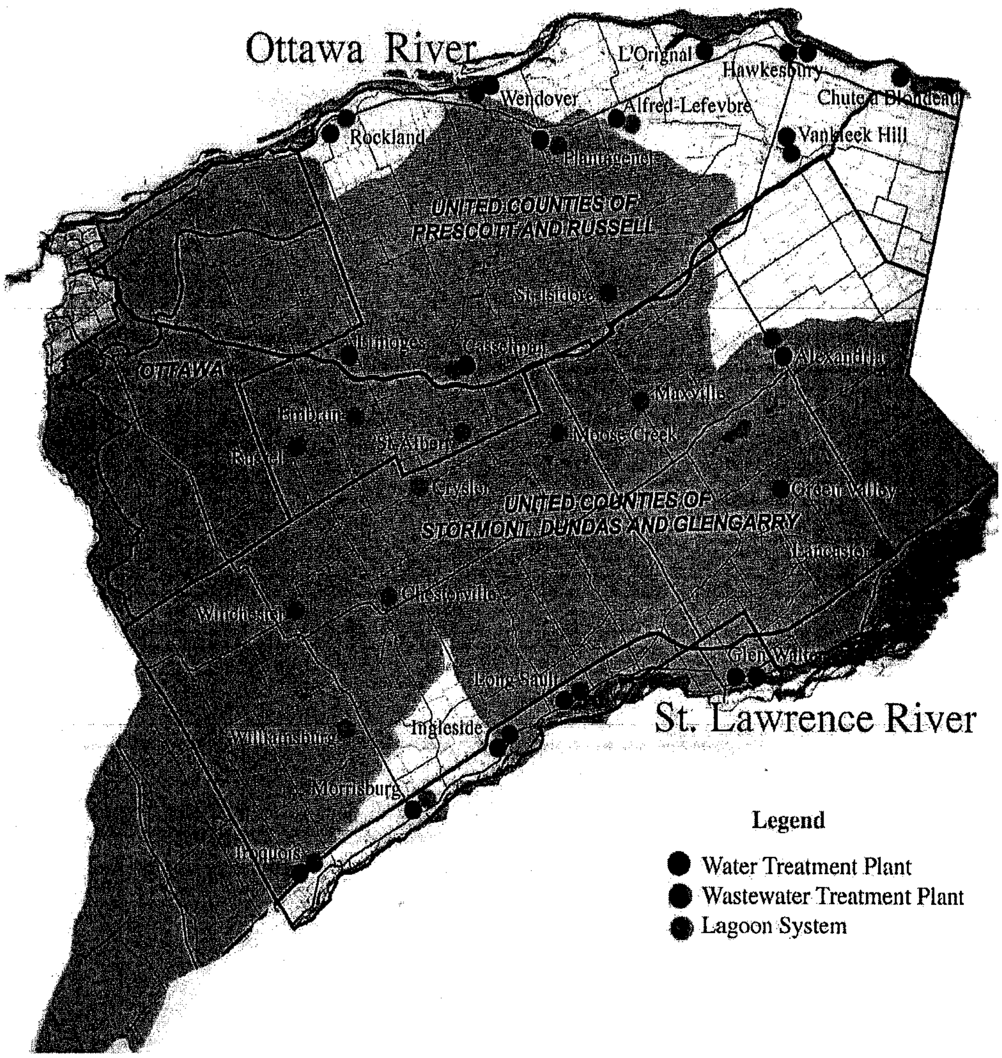


Figure 4.1 **Water and wastewater treatment facilities in the study area** (adapted from EOWRMS, CH2M-HILL, 2001)

4.1.1.1 Water supply and demand

A summary of the survey's results pertaining to water supply aspects is presented in Table 4.1. This summary provides a global picture of the drinking water supply within the region. Municipal consumption of surface water in the Eastern Ontario region is primarily provided by the Ottawa River, the St. Lawrence River and the South Nation River.

Table 4.1 Water treatment plants survey results – Capacity aspects

Facility	Source	Metering	Storage Reservoir	Scarcity	Increased Demand During Dry Spells
Alexandria	Mill Pond	Yes	Yes	Yes	No
Alfred-Lefaivre	Ottawa River	No	n/a	Yes	n/a
Casselman	South Nation River	Yes	n/a	n/a	n/a
Glen Walter	St. Lawrence River	Yes	Yes	No	Yes
Hawkesbury	Ottawa River	partly	Yes	No	Yes
Ingleside	St. Lawrence River	partly	Yes	No	Yes
Iroquois	St. Lawrence River	partly	Yes	No	n/a
Long Sault	St. Lawrence River	partly	Yes	No	Yes
Morrisburg	St. Lawrence River	partly	Yes	No	Yes
Plantagenet	South Nation River	Yes	Yes	No	Yes
Rockland	Ottawa River	Yes	Yes	Yes	Yes
Vankleek Hill	Ottawa River	Yes	Yes	No	n/a
Wendover	Ottawa River	n/a	n/a	No	Yes

n/a: The information was not available

Water scarcity for WTPs that withdraw water directly from the Ottawa and the St. Lawrence Rivers is not a problem at the present time. Nevertheless, water shortages during high demand periods were reported at the Alfred-Lefaivre plant and the Rockland plant (both plants are on the Ottawa River). These water shortages occur when there is a pronounced increase in water demand during dry periods and they are related to limited plant capacity rather than to a limitation of the water source.

Communities that rely on smaller streams or lakes for drinking water supply are more vulnerable to water scarcity. The communities of Casselman and Plantagenet both withdraw from the South Nation River, while the municipality of Alexandria withdraws from the Mill Pond. Alexandria has reported concerns in regards to the capacity of its source of water to provide sufficient water during dry weather conditions, as well as for the increasing water demand caused by population growth. Water treatment plants withdrawing from the South Nation River have not reported water scarcity problems, but the smaller volume of the source is likely to be vulnerable to such problems in a future with more frequent and more intense droughts.

A dramatic drop in water levels during dry periods might cause water intakes to become too shallow, with resulting water quality problems. However, water intakes in the Ottawa and the St.-Lawrence Rivers are between 3 and 10 meter deep and were not reported to be a source of water quality problems when water levels drop during drier periods.

The Plantagenet WTP, located on the South Nation River, experienced water shortages during the 1980s. The water intake was relocated and no further water shortages have been reported. Water intakes on the South Nation River were reported to be 5 to 7 meters deep.

4.1.1.2 Water quality

A summary of the survey's results on water quality issues reported at the WTPs is presented in Table 4.2. The different quality parameters are discussed separately in the following sections.

Table 4.2 Water treatment plants survey results – Quality aspects

Facility	Source	Turbidity Variations	Algae	Taste & Odor	Color
Alexandria	Mill Pond [1]	No	Yes	Yes	n/a
Alfred-Lefaivre	Ottawa River	n/a	n/a	n/a	n/a
Casselman	South Nation River	n/a	n/a	n/a	Yes
Glen Walter	St. Lawrence River	No	n/a	Yes	n/a
Hawkesbury	Ottawa River	Yes	Yes	Yes	Yes
Ingleside	St. Lawrence River	Yes	n/a	n/a	n/a
Iroquois	St. Lawrence River	n/a	n/a	n/a	n/a
Long Sault	St. Lawrence River	Yes	n/a	Yes	n/a
Morrisburg	St. Lawrence River	Yes	n/a	Yes	n/a
Plantagenet	South Nation River	Yes	No	Yes	No
Rockland	Ottawa River	n/a	n/a	n/a	n/a
Wendover	Ottawa River	n/a	n/a	n/a	n/a

1. The Raisin Region Conservation Authority is currently performing a study on the Mill Pond (RRCA, 2004). This study was initiated in order to get a significant assessment of the Mill Pond system, and to develop a series of recommendations for Mill Pond with the goal of improving and/or maintaining water quality. Weekly water sampling begins yearly in mid July and continues until the end of October. Parameters being assessed include: Bacteria levels, Specific Conductivity, Dissolved Oxygen, Temperature, Total Phosphorus and $NH_3 + NH_4^+$.

4.1.2 Wastewater treatment plants

Mechanized wastewater treatment systems within the study area include: sequencing batch reactors (SBR), rotating biological contactors (RBC) and extended aeration activated sludge. A summary of the survey's results pertaining to WWTPs is presented in Table 4.3. Specific topics on wastewater treatment within the study area are developed in the following sections.

Collection systems, which transport wastewater from the residences to the treatment facilities, can be of the combined type (collection of rain water along with the domestic wastewater) or of the separated type (domestic wastewater only). Within the study area, except for some parts of Hawkesbury (old part of the town), all collection systems are separated.

Table 4.3 Wastewater treatment plants survey result

Facility	Receiving Waters	Type of Treatment	Degree of Infiltration	Qww/Qw*	Equalization Capacity	Observations
Chute a Blondeau	Ottawa River	Extended aeration package plant		n/a	n/a	
Glen Walter	St. Lawrence River	Extended aeration	Moderate	1,47	No	During maximum flow events, bypass is practiced
Hawkesbury	Ottawa River	Modified extended aeration	Unknown	0,73	Planned	
Ingleside	St. Lawrence River	Extended aeration	High	1,12	Yes	
Iroquois	St. Lawrence River		Unknown	n/a	No	New Plant is expected in a near future
Long Sault	St. Lawrence River	Sequantial batch reactor (SBR)	High	0,95	No	
L'Orignal	Ottawa River	Extended aeration	High	n/a	No	During maximum flow events, bypass is practiced
Rockland	Ottawa River	Sequantial batch reactor (SBR)	Unknown	1,18	No	
Vankleek Hill	Little Rideau Creek	Rotating biological contactor (RBC)	Low	2,07	No	Certain years, ammonia criteria is exceeded in spring
Wendover	Ottawa River	Rotating biological contactor (RBC)	Unknown	n/a	No	

* based on flows reported by CH2M-Hill (2001)

Depending on the wastewater characteristics and the Certificate of Approval (C of A) determining the effluent quality, specific treatment objectives, such as phosphorus removal, may also be present. It should be noted that all mechanized wastewater facilities of the study area have phosphorus removal. The provincial guidelines for wastewater treatment in Ontario (MOE, 2003a) are presented in Table 4.4. The numbers found in Table 4.4 are guidelines only. The applicable criteria for a given facility are specified on the facility's C of A. When a community applies for a C of A in order to build a facility, the vulnerability of the potential receiving water is evaluated. The MOE issues a C of A that will require the applicant to use a treatment scheme that meets the capabilities of the receiving water (as perceived at that time). Based on the treatment scheme, the standards are incorporated into the C of A. Thus, a plant's effluent standards do not change until the plant is expanded or upgraded and a new C of A is issued. When non-compliances to the C of A criteria are experienced, an investigation is performed and measures are proposed to rectify the situation. If the facility fails to cooperate, fines and charges can be applied (Manoharan, 2004).

Table 4.4 Effluent criteria for wastewater treatment facilities (after MOE, 2003a)

	Effluent Design Objectives				Effluent Guidelines	
Treatment Level and Processes	**BOD_5** (mg/L)	**SS** (mg/L)	**TP** (mg/L)	**$(NH_3+NH_4^+)$-N** (mg/L)	**BOD_5** (mg/L)	**SS** (mg/L)
Conventional Activated Sludge without TP removal	15	15	-	-	25	25
Conventional Activated Sludge with TP removal	15	15	1,0	-	25	25
Contact Stabilization without TP removal	20	20	-	-	25	25
Contact Stabilization with TP removal	20	20	1,0	-	25	25
Extended Aeration without TP removal	15	15	-	-	25	25
Extended Aeration with TP removal	15	15	1,0	-	25	25
Continuous Discharge Lagoon without TP removal	25	30	-	-	30	40
Continuous Discharge Lagoon with TP removal	25	30	1,0	-	30	40
Seasonal Retention Lagoon without TP removal	25	30	-	-	30	40
Seasonal Retention Lagoon with TP removal by batch chemical dosage	15	20	0.5 to 1.0	-	25	25
Seasonal Retention Lagoon with TP removal by continuous chemical dosage	25	30	1,0	-	30	40
Physical-chemical Treatment	20	20	1,0	-	25	25
Conventional Activated Sludge with TP removal and filtration	10	5	0,3	-	—	—
Conventional Activated Sludge with nitrification	15	15	-	<1.0	—	—
Extended Aeration with TP removal and filtration	5	5	0,3	-	—	—

4.1.3 Lagoon systems

Lagoons are relatively shallow bodies of wastewater contained in earthen basins. They have become very popular in small communities because of their low construction and operating costs, providing a significant financial advantage over other treatment methods. Lagoons are usually classified according to the nature of the biological activity that takes place within the lagoon: aerobic, anaerobic, or aerobic-anaerobic (facultative). Facultative lagoons are the most common type and have been used to treat domestic wastewater and a wide variety of industrial wastes (Metcalf and Eddy, 1991). In facultative lagoons, treatment is accomplished by bacterial action in an upper aerobic layer and a lower layer that can be anoxic or anaerobic, depending on wind-induced mixing. Settleable solids are deposited on the lagoon bottom. Oxygen is provided by natural surface aeration and photosynthesis.

The duration and frequency of lagoon discharge can be adapted to the local conditions, in order to obtain adequate treatment and minimize the lagoon's effluent impact on the receiving waters. In eastern Ontario, most lagoon systems discharge twice a year, which provides a hydraulic retention time of approximately six months. This approach also allows discharges at times when instream dilution is greatest, and thus minimizes the impact of the effluents on the receiving waters.

Facultative lagoons in the Eastern Ontario generally provide five-day carbonaceous biochemical oxygen demand ($CBOD_5$) percent removals above 90%, with effluent BOD_5 varying between 5 to 15 mg/L (OCWA, 1998). Suspended solids (SS) percent removals vary significantly from one lagoon system to another, ranging from approximately 50% to approximately 95%. For most lagoon systems of the study area, the effluent SS concentration is between 15-25 mg/L, but in some systems, effluent SS concentration can reach 55 mg/L (OCWA, 1998). It should be noted that the mechanisms present within a lagoon are such that the influent organic loading is ultimately transformed into algae. A portion of these algae is removed from the lagoon with the effluent, in the form of suspended solids. The high concentration of algae will not be reflected in the BOD_5 concentration of the lagoon effluent, but will be reflected in the total COD of the lagoon effluent. The introduction of algae to the receiving waters may have variable longer-term effects, including acceleration of the eutrophication process. Consequently, good performance of lagoon systems on BOD_5 removal does not assure that the effluent will not impair the quality of the receiving waters.

Without the addition of chemicals for precipitation, the removal of phosphorus in lagoons is minimal (Crites and Tchobanoglous, 1998). Chemical addition using alum is used in all lagoon systems within the study area. In most cases, effluent phosphorus is reduced to below 1 mg/L (OCWA, 1998).

Nitrogen removal in lagoons appears to be the result of a combination of mechanisms including volatilization of ammonia, algal uptake, nitrification/denitrification, sludge deposition, and adsorption onto bottom soils. Nitrogen removal data were not available for the facilities within the study area. Studies on lagoon performance in the U.S. (Middlebrooks et al., 1982) reported ammonia-N removals of 20 to 97.5% during winter months (December-March), when the water temperature is between 1 and 5°C. During summer months (June-September), when the water temperature is approximately 20°C, removals were between 67.4 and 98.7%. Hydraulic retention times for these studies varied between 74 and 227 days. Middlebrooks et al. (1982) report that the influent wastewater characteristics (pH, particularly) had a major impact on the ammonia removal rates.

The collection systems transporting wastewater from residences to the treatment facilities are of separate type for all of the study area's lagoons.

A summary of the survey's results pertaining to lagoon systems is presented in Table 4.5. The effluents of lagoon systems are usually discharged in smaller receiving waters and are often of lower quality than the effluents of mechanized plants. For these reasons, discharges from lagoon systems need to be managed so that they occur when in-stream dilution capacity is high, in order to protect water quality and aquatic life. This requirement is reflected by the fact that most existing systems are designed and operated using seasonal or annual discharge. In the study area, discharges generally occur in April-May and November-December.

Table 4.5 **Lagoon systems survey results**

Facility	Receiving Waters	Infiltration	Qww/Qw*	Discharge	System Configuration	Observations
Alexandria	Delisle River	High	n/a	Continuous	1aerated cell followed by 5 cells in parrallel	Max flows dilute wastewater and improve effluent quality-Ammonia not currently removed-Upcoming ammonia criteria is a concern
Alfred	Azatika Brook Creek	n/a	1,96	Annual	Parallel operation followed by wetland treatment pilot project	
Casselman	South Nation River	n/a	1,18	Seasonal	2 cells	
Chesterville	South Nation River	High	0,96	Seasonal	2 cells in series	Algal blooms are always a problem during fall
Crysler	South Nation River	n/a	n/a	n/a	n/a	
Embrun	Castor River	n/a	1,08	Annual	6 cells; 4 primary cells and 2 secondary cells	
Green Valley	Beaudelais River	n/a	n/a	Annual (Mar to May)	n/a	
Lancaster	Finney Creek	n/a	n/a	Seasonal (Apr-Nov)	System oparetad in parallel	Discharge stops during drought and heavy heat
Maxville	Scotch River	n/a	n/a	Annual (November)	2 cells in series	
Moose Creek	Moose Creek	n/a	n/a	Annual	n/a	Spring discharge is delayed when flows are low-algal bloom becomes a problem
Morrisburg	St. Lawrence River	n/a	0,91	Continuous	System operated in series	Quality decreases in August and September
Plantagenet	South Nation River	High	1,41	Seasonal	Single cell	Insufficient hydraulic capacity causes overflow of the lagoon
Russel	Castor River	n/a	1,02	Seasonal	2 cells in series	
St-Albert	South Nation River	n/a	n/a	Annual	n/a	
St-Isidore	Scotch River	n/a	n/a	Annual (May)	3 cells in parallel	
Williamsburg	Mc Martin Drain	n/a	n/a	Annual (April)	2 cells	
Winchester	Henderson Creek	n/a	0,82	Seasonal	5 cells; 4 facultative cells and 1 aerated cell	Seasonal algal bloom which increases SS concentration- High ammonia levels during dry years - attributed to high evaporation and strong sewage because of less infiltration

* based on flows reported by CH2M-Hill (2001)
n/a: not available

4.2 Analysis of potential problems

This section presents an analysis of potential problems that may be exacerbated or induced by climate change.

4.2.1 Water Treatment Plants

As a result of the literature review's information combined with engineering knowledge about the processes involved in drinking water treatment, the following problems were identified as being potentially sensitive to global warming and its climate response:

Supply and demand: more severe droughts could cause more frequent water shortages, especially in late summer and fall when streamflows are lowest and demand is highest. This problem could be further accentuated by an increase in water demand that is usually experienced during a drought period.

Water Intakes: dramatic decreases in streamflows or lakes level could modify the water quality at the location of the intake and create the need to relocate the water intake.

Turbidity: Flushing of storm water and erosion by runoff is likely to increase during more severe rain events, causing an increased turbidity following the extreme rain events. Turbidity from algae could also increase if algal growth increases. Increased algal growth is expected to be particularly evident during warmer lower flow periods of the summer and fall.

Taste and odor: warmer temperatures and lower flows favor increased growth of algae, the most common source of taste and odor problems. It should be noted that, based on phosphorus levels, the South Nation River is considered to be eutrophic (Crabbé and Robin, 2003), and thus is particularly sensitive to such problems.

4.2.1.1 Supply and demand

Municipalities whose distribution system is not metered reported a significant increase in water demand during the summer or during drought periods, ranging from 20% (at Long Sault) to 140% (at Glen Walter).

Municipalities with metered distribution systems also reported increased water demand during dry periods, but to a lesser extent. Figure 4.2 shows monthly water production for the Ingleside and Hawkesbury WTPs, which experienced an increase in water demand of 39 and 20% (maximum versus average flows), respectively, during summer months. It should be noted that for both these municipalities, only industries and part of the businesses are metered.

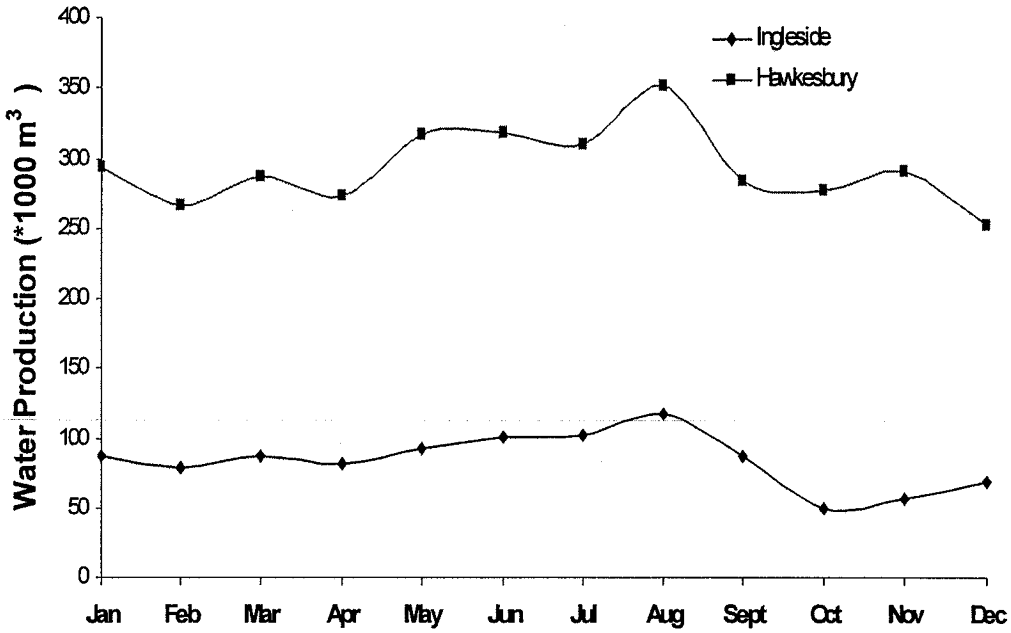


Figure 4.2 Monthly water productions for year 2001 at the Hawkesbury and Ingleside water treatment plants

The increase in demand during dry and hot weather is driven primarily by landscape irrigation (Natural Resources Canada, 2002). The operating authority of the Hawkesbury WTP, which provides water for industries, has also reported an increase in demand during hot weather for industries that require water for cooling purposes (Guertain, 2002).

At the time of the survey (2002), installation of meters on the distribution systems at the Glen Walter and Long Sault WTPs were planned for the a near future. Results similar to those obtained in Alexandria, i.e., a decrease in water demand of approximately 30%, were expected following the metering of these systems.

Of all the facilities that have water metering on there distribution system, only the Alexandria WTP does not experience increase in water demand during summer or dry spells. Figure 4.3 shows that the water production did not increase during summer months. A decrease of water production can be observed in Figure 4.3 for the month of July. This decrease was reportedly caused by an industry shut down. Consultex, a textile industry, uses water from the municipal WTP and shuts down during July. An increase in water production can also be observed for the months of November and December on Figure 4.3, this increase was reportedly the result of water breaks in the distribution system.

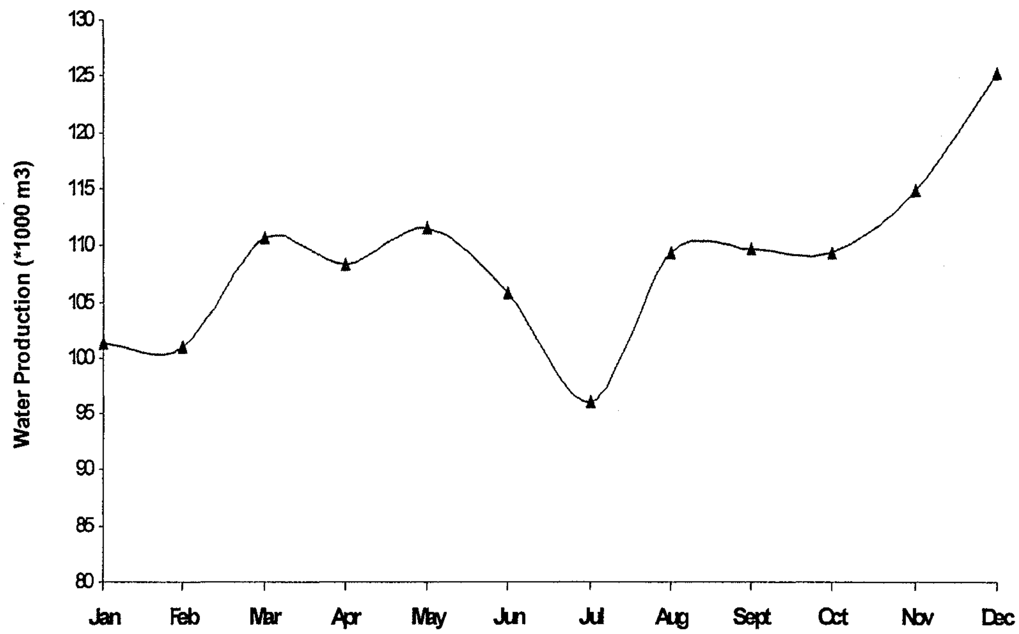


Figure 4.3 Water Production for year 2001 at the Alexandria water treatment plant

4.2.1.2 Water quality

4.2.1.2.1 Turbidity

During heavy rainfalls and snowmelt, turbidity levels are subject to increases as a result of the flushing effect which transports material into the water courses. Figure 4.4 shows an increase in turbidity during spring at the Hawkesbury WTP. Monthly turbidity averages may reach 13 NTU during spring, while monthly average values for the rest of the year range from 1.12 to 3.84 NTU. It should be noted that all of these values are easily manageable by a conventional WTP.

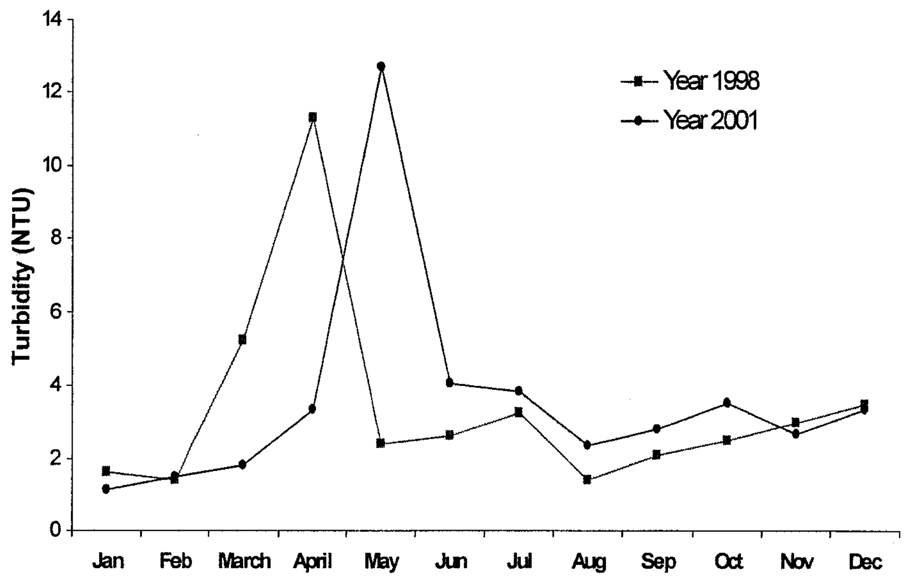


Figure 4.4 Monthly average turbidities for year 1998 and 2001 at the Hawkesbury WTP

During turbidity peaks, an adjustment in coagulant (alum) dosage is usually required to treat the increased turbidity adequately. The operating authority of the Plantagenet plant reported that the increase in turbidity during maximum flow events requires an increase of chemical dosage of approximately 25%. Data to support this affirmation were not accessible.

At the Hawkesbury WTP, where the source of water is the Ottawa River, the main treatment objectives are turbidity removal and disinfection. Raw water turbidity is removed by: a) the addition of alum, which destabilizes the colloids; b) the flocculation, which allows formation of flocs with the turbidity causing particles; and c) the removal of these flocs via precipitation in settling basins and via filtration through sand/anthracite filters. Subsequently the water is disinfected with chlorine prior to distribution. Figure 4.5 presents the variation of alum dosage with raw water turbidity at the Hawkesbury plant for the month of July 2001. The graph shows that, although there is a peak at the beginning of the month, the turbidity values are relatively low throughout the month (all values are below 8 NTU). As a reference, the World Health Organization (WHO) requirement for drinking water turbidity is 5 NTU (WHO, 1996) while the North American turbidity standard is 1 NTU (USEPA, 2001). When considering that turbidity in surface water can reach over 100 NTU; the values presented in Figure 4.5 suggest that the Ottawa River water is relatively clear.

Alum dosages presented in Figure 4.5 seem to vary proportionally with the turbidity level (with a delay of approximately 24 hours) for values in the range of 2.7 to 4.5 NTU. In the case of higher turbidity values, such as the 8.3 and 6.4 NTU, the alum dosage does not seem to vary proportionally to turbidity values. This could be explained by the fact that, in some cases, higher turbidity increases chances of particle contact and agglomeration of destabilized (coagulated) particles. It should be noted that alum doses range between 22 and 48 mg/L (with a mean of ~ 35 mg/L), with a variation of ±40%, this is quite significant, particularly when considering the low turbidity values.

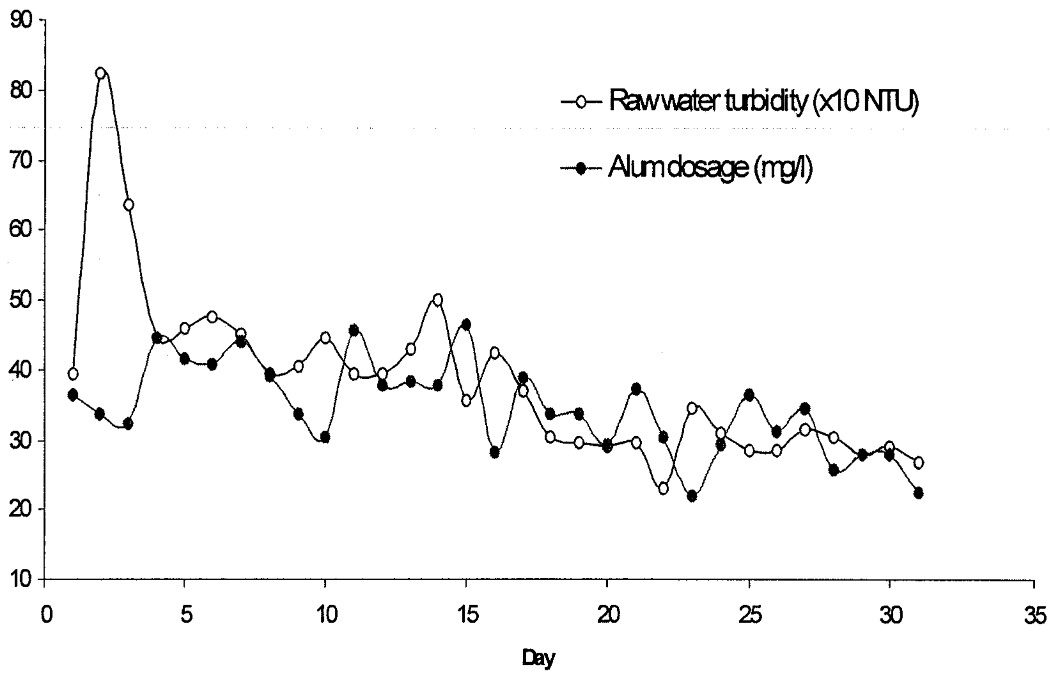


Figure 4.5 Variation of alum dosages with variation in turbidity for the month of July 2001 (at the Hawkesbury WTP)

During the survey, it was reported by OCWA management and operating staff that water from the South Nation River (at Casselman and Plantagenet WTPs) was particularly affected by spring flush and extreme weather events and that the resulting increase in turbidity, odor, color, and pH made the South Nation River water extremely difficult to treat and required very tight control. Based on monthly operating data from the Plantagenet WTP, an analysis of the effect of spring precipitations (using data from St-Albert, station # 6107276) on turbidity was undertaken in order to verify some of the observations reported by local operating staff i.e., increased turbidity and color during spring flush. Figure 4.6 (a) presents the monthly average turbidity and color as well as the monthly precipitation for year 2002 (January through August were the only data available for 2002).

In Figure 4.6 (a), increased color and turbidity are observed during the months of January through June. The precipitation pattern presents a slight increase from February through April, with a precipitation peak during the month of May. In this case, the color and turbidity peak is delayed from the precipitation peak. Because the data are in the form of monthly values, it is not possible to determine if the delay is short or extended (the delay could be as short as twelve hours or as long as thirty days). The data presented in Figure 4.6 (a) indicate that spring precipitation could have for effect to increase the level of difficulty in treating the South Nation River water to produce drinking water.

When looking at Figures 4.6 (b) and (c) however, the impact of spring precipitation does not seem to necessarily generate peaks in turbidity or color. Early spring peaks in turbidity and color seem, to a certain extent, to be independent of spring precipitation regime at Plantagenet, in the South Nation River.

(a)

(b)

(c)

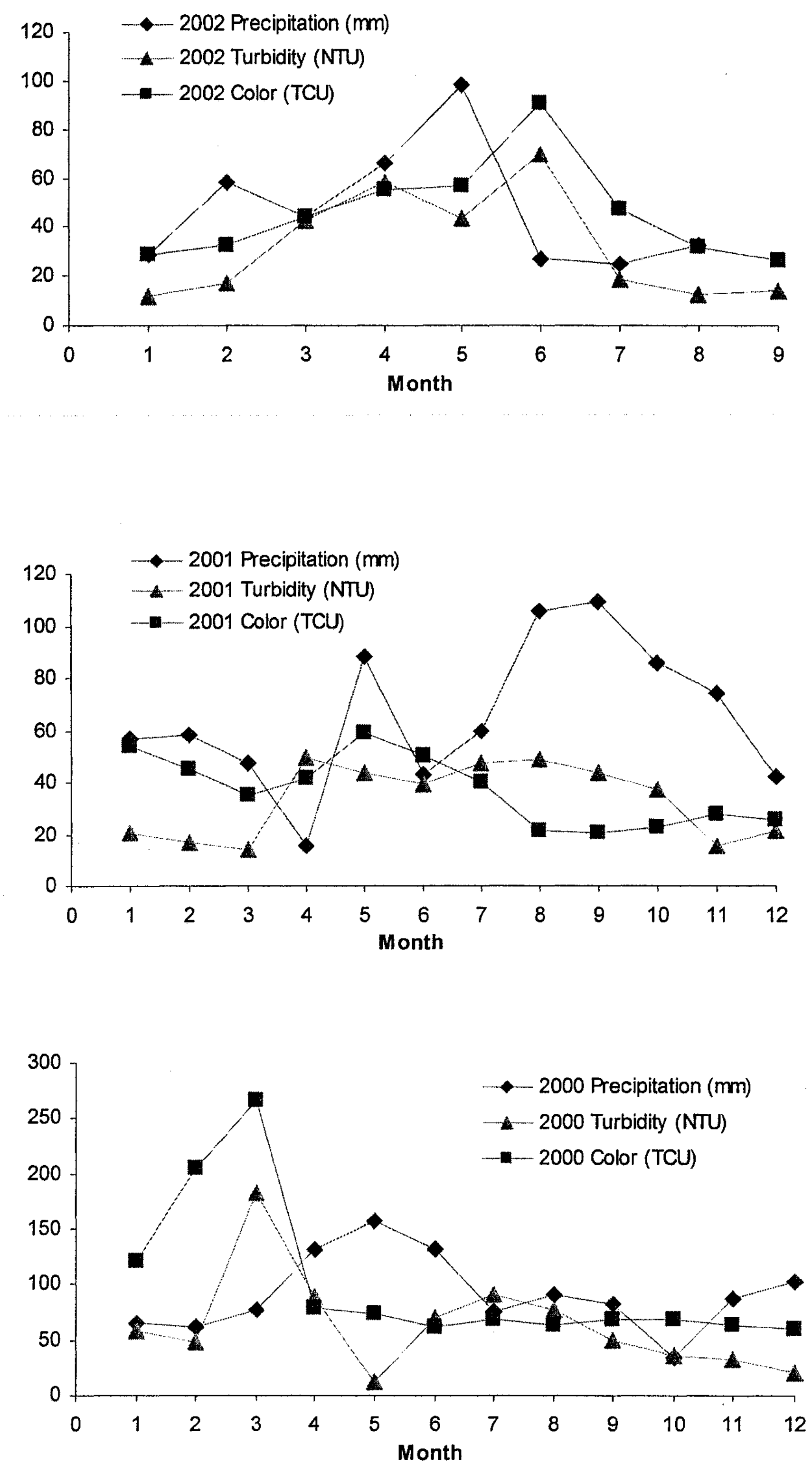


Figure 4.6 Monthly precipitation, average turbidity and average color: (a) 2002, (b) 2001, (c) 2000 (data from Plantagenet WTP and climate station 6107276)

4.2.1.2.2 Taste and odor

Taste and odor problems were reported for all of the region's water sources. The Alexandria WTP, which withdraws water from the Mill Pond, experiences taste and odor problems during the spring and summer. Seasonal algal blooming was reported to be responsible for the problem.

The Plantagenet WTP, that uses water from the South Nation River, has reported odor problems but did not mention algal blooming as a possible source of the problem. It should nevertheless be noted that the South Nation River is considered to be an enriched stream and that it offers ideal conditions for growth of algae (Pick, 2002).

The Long Sault, Glen Walter, and Morrisburg WTPs withdraw their water from the St. Lawrence River. No seasonal pattern or direct link to algal bloom was reported with respect to taste and odor problems by the operating authorities of these facilities. The National Water Research Institute, in its report "Threats to sources of drinking water and aquatic ecosystem health in Canada, 2001" states that the sources of taste and odor creating compounds in the Great Lakes and the St. Lawrence River are still unknown (algae or bacteria). At the Long Sault WTP, taste and odor problems are assumed to be linked to the presence of zebra mussels in the St Lawrence River. After completion of its new WTP in 1987, the Township of South Glengarry added a granular activated carbon (GAC) unit to its Glen Walter WTP in order to treat the taste and odor problems.

The Hawkesbury WTP, withdrawing water from the Ottawa River, has reported an increase in taste and odor during the spring. Local staff reported that this taste and odor increase was the result of the mixing, during spring flows, of the river bottom's heavy organic content left by logging activities. Although the biological decomposition of leaves and weeds (and possibly wood) can lead to the development of odors, taste and odor producing substances are typically released by algae (Tchobanoglous and Schroeder, 1987 and Droste, 1997). It has not been determined which organisms are responsible for taste and odor problems in the Ottawa River. Some scientists (Pick, 2002 and Watson et al. 1999) suggested that chrysophytes, a group of algae typical of oligotrophic, colored waters like the Ottawa River, could be the source of taste and odor problems in that particular river.

It is important to underline the fact that taste and odor are two aesthetic characteristics of water and do not represent a threat to human health as such. Taste and odor compounds are present in parts per trillion concentrations; their analysis involves gas chromatography methods that are complex and expensive. For these reasons, taste and odor are not quantified at WTPs. The problems reported are qualitative and often result from customer complaints, the only quantification being the number of complaints.

4.2.1.2.3 Color

Color problems were reported at the Casselman and Hawkesbury WTPs. As discussed earlier, Ottawa River water is generally clear but it always contains significant color, so much so that Ottawa's treatment plants (located upstream of the study region) have color removal as their primary treatment objective. No details about the possible source of the problem or the conditions (time of the year, climate) during which it occurs were reported at the Casselman plant. At the Hawkesbury plant, it was observed that extreme weather events, such as rain and wind, affect the color of the source water. The color measurement done on raw water is actually the apparent color (i.e., there is no filtration of the samples prior to measurement); readings are therefore affected by turbidity. At these two plants, the turbidity removal with coagulation/flocculation removes most of the color in the water. Note that at Ottawa's WTPs, approximately 90% color removal and 50% TOC removal are obtained with alum concentrations in the 25 to 33 mg/L range (Narbaitz, 2003).

4.2.2 Wastewater treatment plants

For WWTPs, the following problems were identified as being potentially sensitive to global warming and its climate response:

Capacity: A major problem with respect to capacity is inflow and infiltration into the sewer system during rain events. This rainwater swells the normal wastewater flow and causes peak flows that may be too high for the treatment facility to handle properly. The higher flowrates increase the hydraulic loading rates, and consequently possibly decrease the treatment efficiency. In extreme cases it may lead to the loss of biomass from biological processes, which would result in reduced treatment efficiencies for several days.

Impact on receiving waters: Two potential problems with respect to impact on receiving waters are bypass of partially treated wastewater during heavy rain events and reduced dilution capacity of receiving streams during dry periods.

4.2.2.1 Capacity

With the exception of older parts of Hawkesbury and L'Orignal, the municipalities in the study area all have separated wastewater collection systems, i.e., separate sanitary and stormwater sewers. It is important to note that, although almost no drainage water is directed to the region's facilities, rain events can significantly increase infiltration. This may result in significantly greater WWTP influent flowrates. Infiltration problems of various extents are known to exist throughout the region.

An indicator of the degree of infiltration in a collection system is the community's Qww/Qw ratio (wastewater flow (Qww) to water demand flow (Qw) ratio) as presented in Table 4.3. A typical average dry weather wastewater flow is in the range of 80 percent of the water demand (Quasim, 1994). This number accounts for the portions of the water lost due to lawn sprinkling, street washing, and leakage from the distribution system. Using the Qww/Qw ratios from Table 4.3, it can be assumed that some of the region's collection systems have high infiltration rates. The communities of Glen Walter, Rockland, and Vankleek Hill have Qww/Qw ratios of 1.47, 1.18 and 2.07, respectively; these values are considerably high. Other factors could explain such high Qww/Qw ratios, for instance, some residences may have the sewer service but have a private well. Some industries may also have their own water intake and discharge their effluent into the sewer system.

Figure 4.7 presents monthly precipitation as well as the Morrisburg WWTP monthly flows for year 1998. In March, the volume of wastewater treated at the Morrisburg WWTP (230 000 m^3) was almost double that of the annual average monthly flowrate (180 000 m^3); this peak was likely caused by infiltration resulting from a combination of high precipitation and snowmelt. High monthly precipitation values outside of snowmelt period, such as 145 mm in June, also seemed to have an impact on the WWTP flowrate, but to a much lesser extent (increase of approximately 25% of the flowrate). This increase of flowrate in times of high precipitation is an indication that there is infiltration in the collection system. Among the Eastern Ontario region's municipal personnel interviewed, individuals from three municipalities have reported high degrees of infiltration.

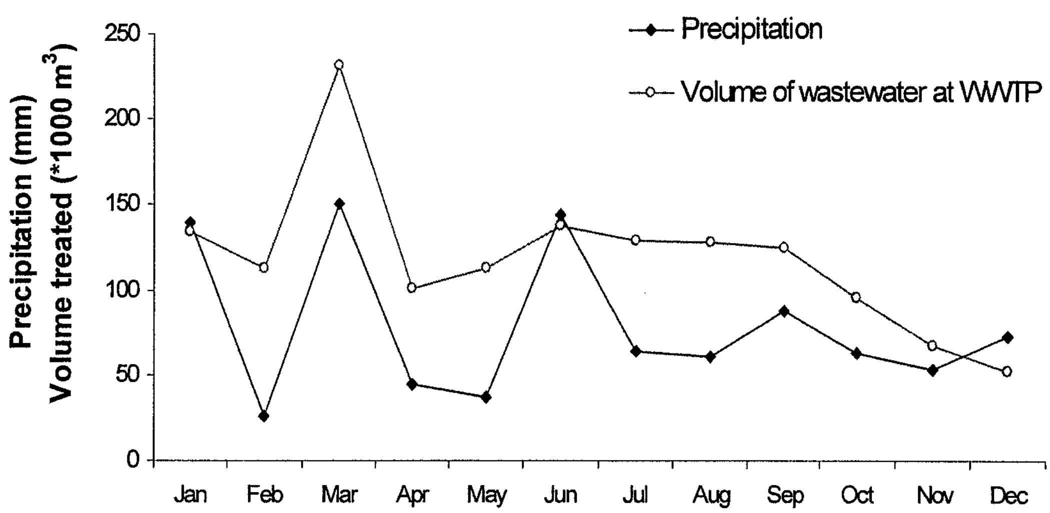


Figure 4.7 Relation between precipitation and volume of wastewater
(1998 data –Morrisburg WWTP)

As a result of peak flows experienced during maximum precipitation events, some plants (including L'Orignal and Hawkesbury) have to bypass part of the wastewater from the whole treatment train during these events. In many cases, the wastewater is bypassed after primary treatment, and then mixed with the treated water before disinfection and discharge to the receiving waters.

Some municipalities, such as Glen Walter and L'Orignal have performed rehabilitation works on their collection systems in order to reduce the infiltration problems (Kiloran, 2002; Wilkinson, 2002). Other municipalities have investigated and disassembled illegal connections to the collection systems, significantly decreasing the amount of diluted wastewater arriving at the WWTPs. Actual percentages of infiltration reduction as a result of these practices were not available.

When peak flows are directed to wastewater treatment facilities, a certain equalization capacity is provided by pumping stations, which are encountered at the head of all treatment plants. This equalization capacity, however, is limited and will not be sufficient to regulate high flow variability. At the time of the survey, the Municipality of Hawkesbury was planning to build an equalization basin in order to increase the plant's capacity during peak flows and minimize the need for bypassing.

4.2.2.2 Impacts on receiving waters

As discussed in the previous section, bypassing may occur during periods of heavy precipitations. The bypass of part of the inflow from the main treatment train allows for the treatment conditions within the plant to be protected so that when flows return to normal volumes, they can be treated adequately. However, bypassing results in the discharge of partially treated wastewater to receiving streams.

Due to decreased water flows during drought periods, small bodies of water which receive effluent from wastewater facilities lose dilution capacity.

In either case water quality in the receiving waters may be degraded, with potential impacts on aquatic life, downstream WTPs and other beneficial uses.

4.2.3 Lagoon systems

For lagoon systems, the following problems were identified as being potentially increased by global warming and its climate response:

Capacity (continuous discharge lagoons): A major problem with respect to capacity of continuous discharge lagoons is inflow and infiltration into the sewer system during rain events. This rainwater swells the normal wastewater flow and causes peak flows that may result in incomplete treatment of the wastewater before discharge.

Capacity (annual or seasonal discharge lagoons): Lagoon systems that operate with annual or seasonal discharge have to hold the total volume of wastewater accumulated between discharges. In case of wet years or wet seasons, this volume might exceed the lagoon's design capacity. However, the overall global warming future trend would lead to greater evapotranspiration losses from the lagoon, as well as from any surface runoff that would normally end up in the lagoon so that, on the average, exceeding the lagoon's capacity may actually be less of a problem. Thornthwaite (1948) developed a method for estimating potential evapotranspiration. This method uses temperature and a heat index variable to determine potential evapotranspiration with the following formula:

$$PE = \frac{1.6\,T^{a}}{I} \qquad (2)$$

where PE is the potential evapotranspiration, T is the temperature in C° a, a constant, and I the heat index (according to average monthly temperatures).

Impact on receiving waters: Lagoon systems may result in the degradation of water quality in receiving waters, and these problems may be exacerbated by climate change. These problems include discharge of partially-treated wastewater, reduced dilution capacity, and growth of algae. Discharge of partially-treated wastewater to small, vulnerable streams may occur as a consequence of inadequate capacity. During drought periods, small bodies of water which receive effluent from lagoons lose dilution capacity. The growth of algae within the lagoon is favoured by warm temperatures and dry weather (lower volume of water at lagoon facilities). The effect of temperature on algal growth has been extensively studied; Dauta (1982), described algae growth as a function of temperature with the following equation:

$$\mu\,(T) = A * T^{2} + B * T + C \qquad \text{for } 15°C < T < 35°C \qquad (3)$$

where μ is the growth rate in d^{-1}, A, B and C are modeling parameters related to maximum growth rate and optimal growth temperature developed for a particular species. Using this equation for the *anabaena cylindrical* algae, a freshwater phytoplankton species (with A=-0.0016, B=0.1031 and C=-0.904), a 10 degree temperature increase from 15 to 25°C, would double the growth rate of that particular algal species.

4.2.3.1 Capacity (continuous-discharge lagoons)

The Alexandria continuous-discharge lagoon system did not report problems related to insufficient capacity during high flow periods. At the Morrisburg continuous-discharge lagoon, insufficient hydraulic capacity was reported to result in incomplete treatment of the wastewater during high flow periods.

4.2.3.2 Capacity (annual- and seasonal-discharge lagoons)

The majority of annual- and seasonal-discharge lagoon systems did not report capacity problems during wet years or wet seasons. The discharge schedule is specified on the facility's C of A and usually allows for flexibility. The Plantagenet lagoon was the only facility where overflow problems during wet weather were reported. At the Lancaster lagoon, the seasonal discharge is stopped in times of dry and hot weather, allowing for protection of the receiving stream (as reported by the local staff).

4.2.3.3 Impact on receiving waters

Problems with respect to impact on receiving water due to lagoon systems in the study area include algal blooms within the lagoons which resulted in high effluent SS and BOD and insufficient hydraulic capacity which resulted in shortened hydraulic retention time and incomplete treatment of the wastewater, as well as limited ammonia removal provided by the lagoons. Improved effluent quality during wet weather periods was observed at some lagoon facilities. At these locations (Alexandria and Winchester lagoon systems), where significant infiltration problems were reported, it was suggested by the local staff that the resulting dilution of wastewater actually improved the effluent quality. At the Morrisburg lagoon, where the discharge is continuous throughout the year, it was reported that insufficient hydraulic capacity (the system was operating at 200% of capacity in 2002) was responsible for non-conformances with the MOE's SS, BOD and TP guidelines. Personnel at this facility also reported that effluent quality usually decreases in August and September. SS values around 100 mg/L, TP values around of 1.5 mg/L and BOD values around 80 mg/L were observed during the months of August and September 2002. High BOD levels could be explained by the dieoff of algal blooms in the fall (Willcocks, 2000). A shortened hydraulic retention time caused by the insufficient capacity of the lagoon system could result in incomplete treatment of the wastewater. The required BOD, SS and P removals may therefore not be achieved before discharge. Another factor that could explain the poor effluent quality during August and September may be the occurrence of algal blooms in late summer within the lagoon.

The Plantagenet lagoon, which was operating at 119% capacity in 2002, has also reported exceedances of MOE's SS guideline. Different solutions are currently being analyzed in order to remediate the capacity problem. These include a further addition of cells to the lagoon system or the implementation of continuous discharge instead of the current seasonal discharge. The operating entity of this facility cites algal growth as contributing to the elevated SS concentrations in the effluent.

The operating authority of the Chesterville lagoon reported that algal blooms were a constant problem during fall, resulting in SS levels of around 30 mg/L (while the guidelines limit the effluent concentration for SS to 20 mg/L). Algal blooms during spring discharge were also reported to be responsible for non-compliance with the SS guideline at the Maxville Lagoon.

At the Moose Creek lagoon, a delay in the spring discharge reportedly caused a quick formation of algal growth (within 2 days after ice cover had melted). This algal bloom increased the SS of the effluent (no concentration values were available). Such delays in annual or seasonal lagoon discharge may occur during dry years or dry seasons, when the lagoon water levels are low. Low spring streamflows due to limited snow accumulation during warm winters or low spring precipitations may also delay spring lagoon discharge. In this case the objective of the delayed discharge is to protect the stream water quality.

4.3 Application of a cost-estimation model (CAPDET)

Due to low construction and operational costs, lagoon systems are widely used for the treatment of domestic wastewater in small rural communities (Crites and Tchobanoglous, 1998). In addition to their low capital and operational costs, lagoon systems offer the advantages of requiring minimal operational skills, extended periods between sludge removal, as well as compatibility with land and aquatic treatment processes.

However, there are a number of disadvantages associated with lagoon systems. In particular, these include the problems of impact on receiving waters, as described in

Section 4.2.3.3. Lagoon systems are a less-advanced type of treatment than mechanized WTPs. It may be difficult or impossible for non-aerated lagoons to meet stringent effluent criteria. Taking into consideration the possible impacts of climate change, these disadvantages may become particularly problematic as they are expected to increase with intensified droughts, more extreme rain events, and warmer temperatures. Independent of climate change, lagoons might not even ensure compliance with future, more stringent effluent criteria (ammonia, for example).

Typically, lagoon systems that are currently operating at or near maximum capacity are waiting for funding in order to proceed with expansion or construction of replacement facilities. Many of the municipalities that treat their wastewater through lagoon systems are considering building mechanized WWTPs. However, the financial issues associated with the upgrade, expansion, or replacement of lagoon systems in this rural region are particularly challenging, as most of the communities have small taxbases, with populations that range between under 1000 and 5500 inhabitants.

One of the main parameters that impacts the construction costs of a wastewater treatment facility is the capacity of the installation because the cost per capita dramatically decreases with increasing capacity due to economies of scale (Boller, 1997; Tsagarakis et al., 2003). The objective of this section is to generate cost estimates for construction of mechanized secondary WWTPs for small communities. This will help communities in the region evaluate secondary treatment as an alternative to lagoon systems. The cost estimates for secondary level of treatment were developed using CAPDET, a program for estimation of costs for wastewater treatment facilities. In order to verify the reliability of CAPDET for small facilities with secondary levels of treatment, the results obtained with CAPDET were compared with the actual costs of several facilities in Ontario and Québec.

4.3.1 The CAPDET model

The CAPDET model was developed by the U.S. Army Corps of Engineers for the U.S. EPA to facilitate the evaluation of wastewater treatment alternatives (Harris et al., 1982). CAPDET, which is primarily designed as a cost estimating model, uses both parametric and unit cost estimating techniques (Harris et al., 1982). The parametric cost estimating is based on a statistical approach, i.e., statistical analysis of the cost of facilities of similar size and characteristics at other locations. Unit cost estimating is based on identification of cost elements to which input unit prices are applied. Unit cost estimating is used to compute the construction cost of each unit process. Additional site-specific costs are addressed through use of statistically generated cost curves based on average costs from different cities within the United States. Given site-specific wastewater characteristics along with a wastewater treatment scheme, CAPDET will estimate the applicable capital and operating costs. The capital cost estimation produced by CAPDET includes direct, indirect, land, and interest costs during construction. Direct costs are the actual construction expenses of the project, such as equipment, labor, and materials. Indirect costs include engineering, legal fees, inspection, and contingencies. Indirect costs, land costs, and interest costs during construction are entirely under the user's control. The indirect costs are calculated as a percentage of the total construction costs; if the user does not specify a percentage, CAPDET will select the value from its default database.

CAPDET uses a three-step process for unit process design and cost estimating (Harris et al., 1982). Figure 4.8 presents this process in a schematic form. The process design calculations section (first-order design) is the basic sanitary process design of the proposed treatment chain. This design level identifies such items as volume of tankage, air requirements, etc. The quantities calculations section (second-order design) identifies and quantifies the major cost items, i.e., volume of earthwork, volume of concrete, equipment size, etc. The third order design section calculates the unit process costs by applying input unit prices to the quantities and sizes calculated in the quantities calculations section.

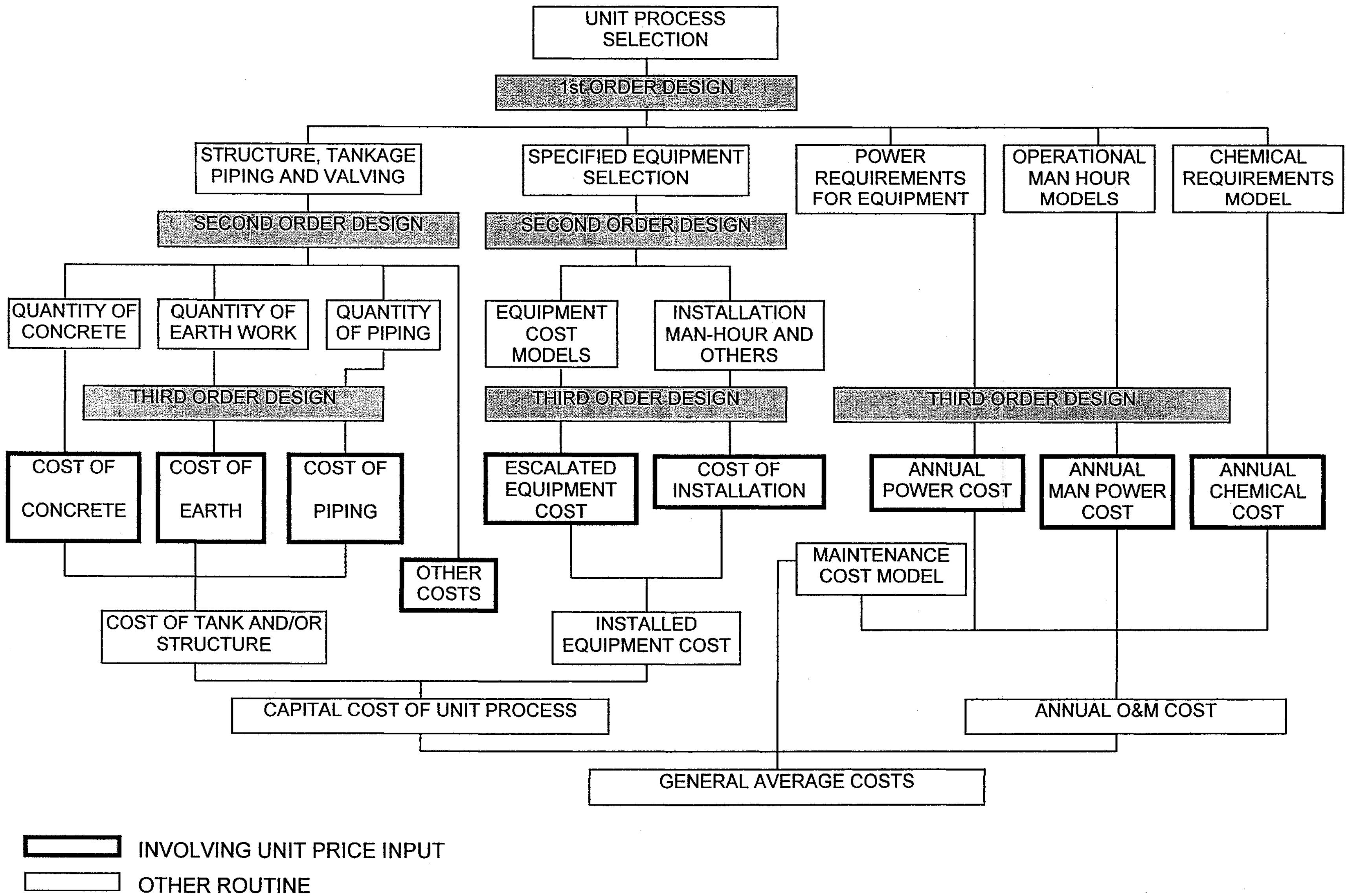


Figure 4.8 **CAPDET algorithm development logic diagram** (after : Harris et al., 1982)

CAPDET was designed to be applicable to all ranges of flows (Harris et al., 1982). Planning level estimating accuracy with CAPDET has been defined as ± 15% for capital costs and ± 20% for operation and maintenance. For small flows (38 to 1890 m^3/d), the process input to the model should be the activated sludge plant package unit (Harris et al., 1982). In practice, package plant units are often used for the treatment of wastewater for individual properties and small communities (Metcalf & Eddy, 1991).

4.3.2 Using CAPDET with Canadian Conditions

Wright et al. (1988) developed a procedure for applying CAPDET to the capital cost estimation of Canadian WWTPs without altering the software source code. The procedure is based on plants with flows ranging from 550 m^3/d and 13 600 m^3/d.

Since CAPDET was developed for use in the US, currency exchange from US to CDN is an obvious concern. Wright et al. (1988) reported that the problem of substituting Canadian dollars for US dollars was studied in detail and that it was found that the cost of wastewater treatment equipment from Canadian suppliers, expressed in 1977 Canadian dollars, was approximately the same as the default equipment costs expressed in 1977 US dollars used in CAPDET. Thus, at the time the study was constructed (1981), it was concluded that the currency exchange rate need not be considered when CAPDET is used in Canada, provided the appropriate inflation index values were used and the equipment was manufactured in Canada.

The procedure for modifying CAPDET to Canadian conditions is based on a systematic adjustment of the unit costs and the determination of a global adjustment factor. In addition, because Canadian design and construction practices are somewhat different from those in the US, primarily owing to differences in the climate, wall concrete, slab concrete, and excavation costs were increased by 15, 50, and 25%, respectively (Wright et al., 1988). The final step in the proposed procedure was conducted following an examination of the resulting cost estimates. The average error from the data was approximately 15% above contract cost. Hence all capital costs estimates from CAPDET were further reduced by 15%. This global adjustment factor accounts for corrections in inflation indices, differences in labor rates and cost of materials, as well as equipment importation costs. The proposed methodology was tested over a 15 year construction period, which indicates that it is not likely to be quickly outdated (Wright et al., 1988).

The procedure developed by Wright et al. (1988) can be summarized as follows:

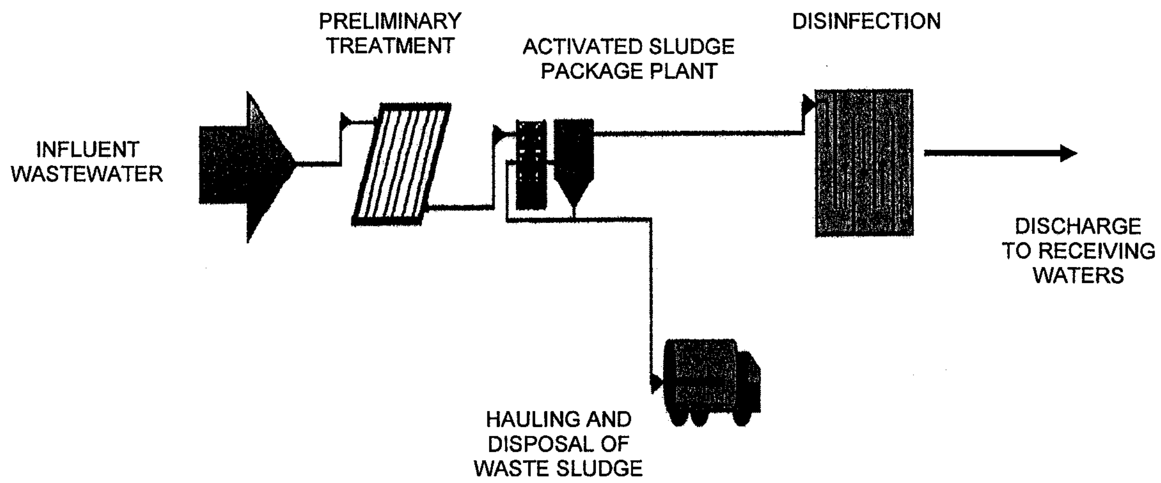
1. All default inflation index values must be changed to the value at the appropriate date.
2. All default unit component costs are adjusted to appropriate date using the average Canadian ENR construction Index.
3. The cost of wall concrete, slab concrete, and excavation must be increased by an additional 15, 50, and 25%, respectively to account for differences in structural engineering.
4. A reduction of 15% in the cost estimate is required to compensate for the overestimation due to Canadian conditions.

4.3.3 Cost Analysis

The cost analysis is performed on capital costs of facilities. The capital costs include the direct construction costs, the indirect construction costs, and the land. In order to be able to use this analysis as a reference tool for the small communities within Eastern Ontario, the range of flows of interest is from 300 to 7000 m^3/d. As per Harris et al. (1982), the process input to the model for small flows (38 to 1890 m^3/d) should be the activated sludge plant package unit. The cost estimate is performed in two sections: one for flows ranging from 300 to 5000 m^3/d and one for flows ranging from 500 m^3/d to 15 000 m^3/d. It was decided to leave very small capacities (38 to 500 m^3/d) out as they are not representative of the project facilities of interest. Plants at the higher end of the range (7 000 to 15 000 m^3/d), were included in the analysis in order to compare the estimates results with available existing data. The package plant and the conventional activated sludge treatment process layouts on which the model estimates were based are presented in Figures 4.9 (a) and 4.9 (b), respectively.

The package plant [Figure 4.9 (a)] is preceded by preliminary treatment and a chlorination unit is added at the plant's effluent. The waste sludge is hauled for disposal. The activated sludge process [Figure 4.9 (b)] includes preliminary treatment, primary clarification, conventional activated sludge, secondary clarification and disinfection, as well as aerobic digestion, belt filter pressing and hauling and land filling for the treatment and disposal of sludge.

(a)



(b)

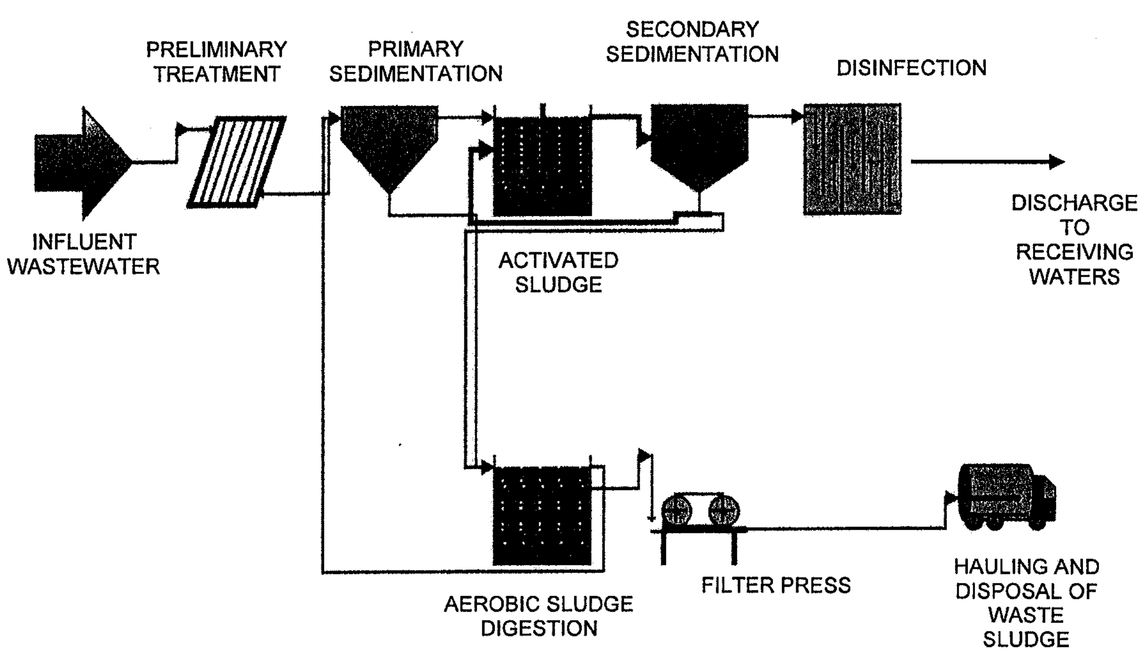


Figure 4.9 Design layout used with the CAPDET estimation software (a) package plant design, (b) small WWTP built onsite

Table 4.6 presents the input values into the CAPDET model (as per the procedure presented in Wright et al., 1988), all the other values were set to default values.

Table 4.6 Input to CAPDET using the Wright et al. (1988) procedure

UNIT COST DATA	ADJUSTMENT OF UNIT COSTS TO CANADIAN CONDITIONS	
Building Cost	969.00 x ENR [a]/6221	$/m^2$
Excavation Cost	10.50 x ENR/6221 x 1.25	$/m^3$
Wall Concrete	654.00 x ENR/6221 x 1.15	$/m^3$
Slab Concrete	458.00 x ENR/6221 x 1.50	$/m^3$
Crane Rental	150.00 x ENR/6221	$/hr
Canopy Roof	172.00 x ENR/6221	$/m^2$
Hand Rail	246.00 x ENR/6221	$/m
Construction Labor Rate	25.00 x ENR/6221	$/hr
Operator Labor Rate	20.00 x ENR/6221	$/hr
Average Administration	20.00 x ENR/6221	$/hr
Pipe Installation Rate	50.00 x ENR/6221	$/hr
8 in Pipe	272.00 x ENR/6221	$/m
8 in Bend	800.00 x ENR/6221	$
8 in Tee	350.00 x ENR/6221	$
8 in Valve	3400.00 x ENR/6221	$
Marshall And Swift Index	1124 [b]	
Engineering News Record Index	6690 [c]	
Pipe Cost Index	580 [d]	

[a, c] Engineering News Record Index, December 2003 (McGraw Hill Construction, 2003)
[b] Marshal And Swift Index, year 2003 (Chemical Week Publishing, 2004)
[d] Pipe Cost Index, December 2003 (Chemical Week Publishing, 2004)

A reduction of 15% in the output cost estimate was further applied to compensate for the overestimation due to Canadian conditions (Wright et al., 1988).

Based on the layout designs (Figure 4.9) and the data input (Table 4.6), a sensitivity analysis was performed with CAPDET in order to observe the impact of plant size (capacity) on the cost of the facility. The sensitivity analysis was performed for flows varying from 100 to 5 000 m^3/d for package plant units and from 510 to 15 000 m^3/d for the conventional activated sludge plants. In order to better visualize the impact of plant capacity on costs, many authors (Tsagarakis et al., 2003; Boller, 1997; Qasim, 1994) present the costs in terms of unit cost ($/$m^3$, which indicates the cost per cubic meter per day for the design capacity as opposed to the actual operating daily volume); this approach is also selected for the present analysis. CAPDET's sensitivity analysis of the impact of influent wastewater flow on the project cost is in terms of total cost for the facility. The sensitivity analysis presents separate curves for present worth, capital costs, operational costs, maintenance costs, energy costs, and chemical costs. The capital cost values from the sensitivity analysis were further divided by the plant's capacity in order to obtain unit capital costs of wastewater treatment.

An important issue with the use of the method presented by Wright et al. (1988) is that it was developed using an earlier version of CAPDET Works. This present analysis is performed using CAPDET Works 2.0 (Hydromantis, Hamilton. ON), which has an equipment cost database from 2000. The procedure developed by Wright et al. used an equipment cost database from 1977, which was assumed by Wright et al. (1988) to be equivalent to Canadian costs, assuming that the equipment was manufactured in Canada. In search for the best option for using CAPDET with Canadian currency, estimates were performed with both the 1977 and the 2000 equipment cost database, the results are presented in Figure 4.10. It can be seen from Figure 4.10 that whether using the 1977 or the 2000 equipment cost database, the package plants are significantly cheaper for flows up to 5000 m^3/d and more. Figure 4.10 also indicates that the estimates performed with the 1977 database do not give the high cost values that should normally be expected for very small WWTPs (flows lower than 500 m^3/d). In practice, it has been shown that there should be a dramatic increase in unit costs for flows lower than 300 m^3/d, (Boller, 1997; Balmér and Mattsson, 1994; and Evans et al., 1993). It can also be observed that the discrepancy between the "Package Plant-1977" curve and the trend towards high values found in practice is not observed for the estimates performed with the 2000 equipment cost database. It is likely that the 1977 equipment database is not reliable for flows lower than 500 m^3/d; thus the 2000 equipment cost database seems to better represent the real costs of building small WWTPs.

It should be noted that the flows used for the sensitivity analysis likely pass through one or more discontinuities in the CAPDET model. The transitions from one algorithm to another are not always smooth, which may explain the irregularities observed in the curves (Copp, 2004).

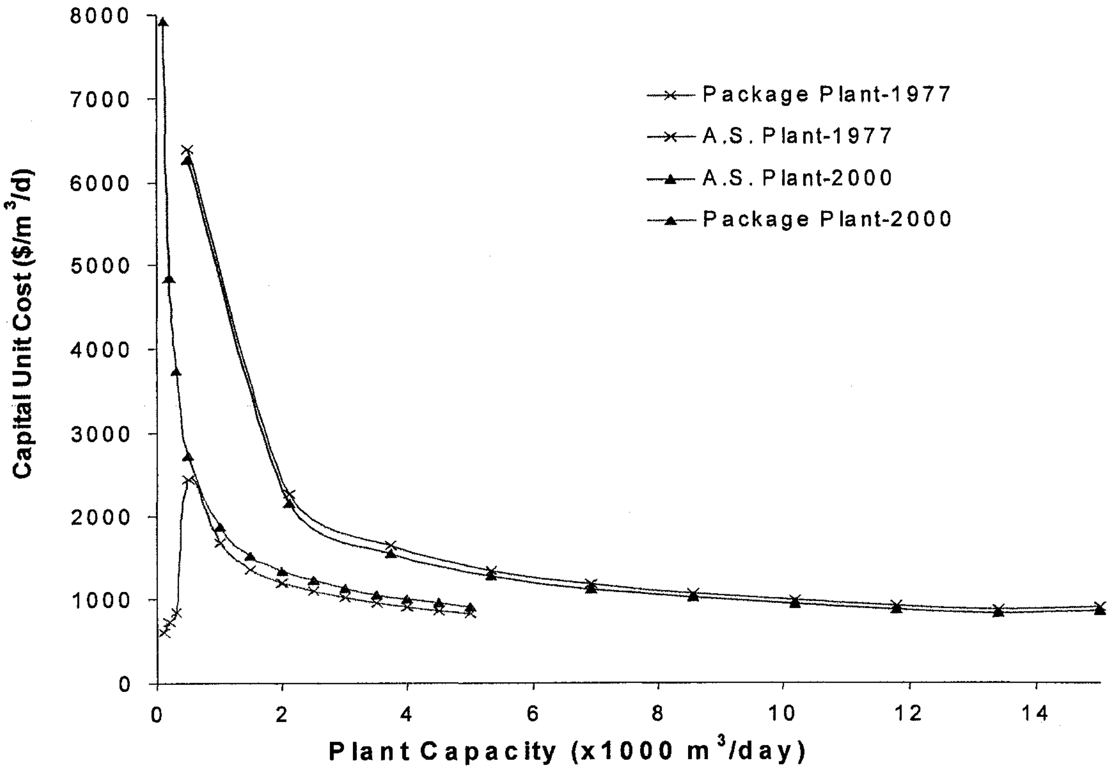


Figure 4.10 Sensitivity analysis with CAPDET using the 1977 and the 2000 equipment costs databases

For flows greater than 500 m^3/d, Figure 4.10 reveals that for the conventional activated sludge process, the 1977 database based estimate is higher by approximately 5% than the estimate based on the 2000 database. For package plants, on the other hand, the 1977 database based cost predictions are approximately 11% lower than those based on the 2000 database [CAPDET's level of accuracy is of ± 15% (Harris et al., 1982)]. It is likely that the 2000 equipment costs database is more representative of the current trends in equipment costs (especially when considering flows lower than 500 m^3/d). Furthermore, for flows greater than 500 m^3/day, the estimates obtained with the 1977 and the 2000 databases are very similar. For the previously mentioned reasons, it was decided to accomplish the remaining of the work using the estimates resulting from the 2000 equipment cost database.

4.3.3.1 Suppliers Unit Costs

The procedure developed by Wright et al. (1988) provides a method that allows using CAPDET for Canadian conditions without any need for external data except for the appropriate inflation index values. However, this method does not necessarily reflect the local unit cost conditions. CAPDET estimates were performed using local unit costs as presented in Table 4.7. These estimates were computed based on the hypothesis that the 2000 equipment costs database was equivalent to Canadian values (Wright et al., 1988). The unit costs were obtained from local suppliers during the February-March 2003 period and no additional adjustments to the CAPDET output were performed. Figure 4.11 presents the CAPDET estimates for both the Wright et al. (1988) procedure and for a conventional use of CAPDET with local supplier information. For the conventional activated sludge plant process, the difference between the two estimation methods ranges from 0 to 1.5% for flows under 10 000 m^3/d, and goes up to 7% for flows as high as 15 000 m^3/d. When looking at the unit costs input values for both estimation methods (Table 4.6 from previous section and Table 4.7), important discrepancies between the two tables values are observed (for example, the unit cost provided by local suppliers for wall concrete is 300 \$/m^3, while applying the Wright et al. (1988) method results in a unit cost for wall concrete of 810 \$/m^3).

Table 4.7 Input to CAPDET using suppliers data

UNIT COST DATA	UNIT COSTS PROVIDED BY SUPPLIERS	
Building Cost	450	$/m^2$
Excavation Cost	300	$/m^3$
Wall Concrete	200	$/m^3$
Slab Concrete	5	$/m^3$
Crane Rental	150	$/hr
Canopy Roof	172	$/m^2$
Hand Rail	200	$/m
Construction Labor Rate	40	$/hr
Operator Labor Rate	30	$/hr
Average Administration	25	$/hr
Pipe Installation Rate	60	$/hr
8 in Pipe	300	$/m
8 in Bend	386	$
8 in Tee	882	$
8 in Valve	3750	$
Marshall And Swift Index	1124 [a]	
Engineering News Record Index	6690 [b]	
Pipe Cost Index	580 [c]	

[a] Marshal And Swift Index, year 2003 (Chemical Week Publishing, 2004)
[b] Engineering News Record Index, December 2003 (McGraw Hill Construction, 2003)
[c] Pipe Cost Index, December 2003 (Chemical Week Publishing, 2004)

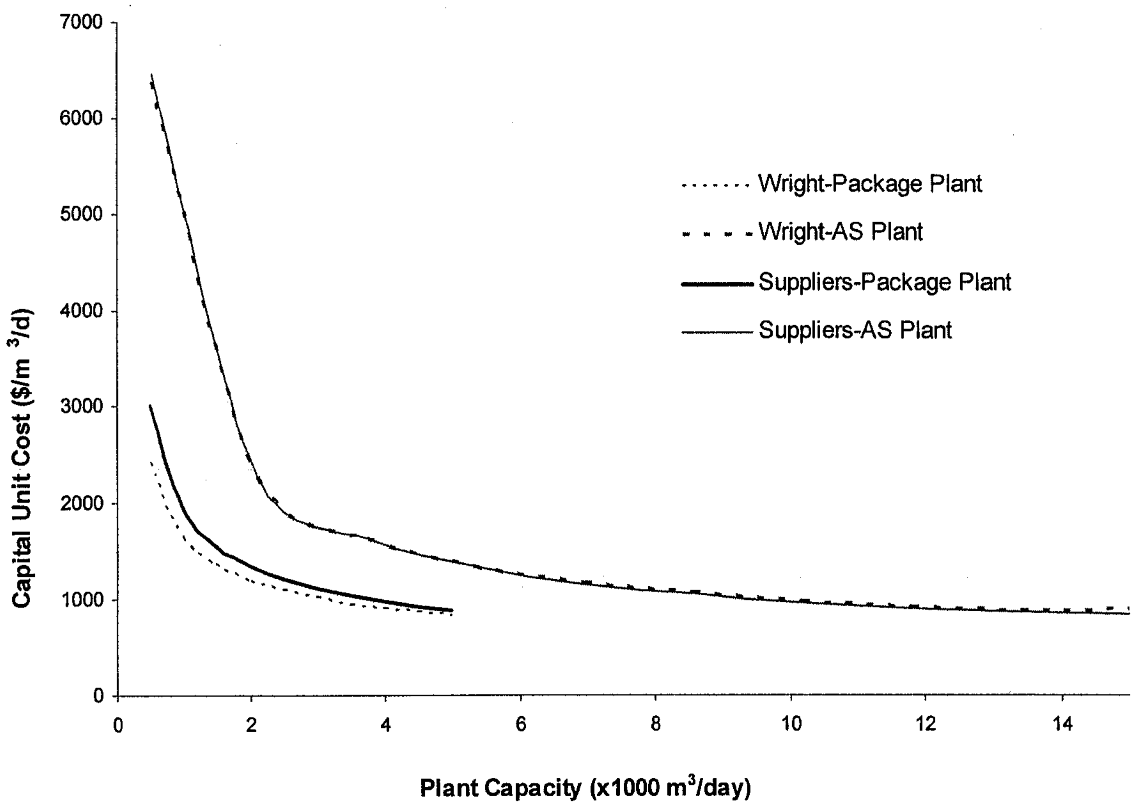


Figure 4.11 CAPDET capital costs estimates using the Wright et al. (1988) and the suppliers unit costs methods

The unit cost values resulting from the Wright et al. (1988) procedure seem to absorb additional costs rather than just reflecting the unit cost for building wall concrete, as the suppliers would normally present it. Nevertheless, once the complete Wright et al. (1988) procedure has been applied, the resulting estimates are very similar to the estimates resulting from the local supplier inputs with differences between 0 and 7% (Figure 4.11). In the case of the package treatment plant, the resulting estimates are not as close, the estimates performed with the local supplier data are higher by 6 to 19%, with the greater difference for smaller flows (flows in the range of 500 m^3) than the estimates provided by the Wright et al. (1988) procedure. It is difficult to explain this difference, it may be because the greatest part of the estimate is from the equipment costs database (as the plant itself constitutes a piece of equipment) and from other indirect costs rather than from unit costs; as such, local unit costs input do not have much impact on the total capital cost. As per Wright et al. (1988), there could be a need for a 15% reduction in the CAPDET output to better reflect the Canadian particularities.

4.3.3.2 Field Data

In order to verify the reliability of CAPDET, the cost predictions were compared with actual costs of past constructions, as well as values found in the literature. The plants for which cost data were available ranged in capacity from 1 500 to 13 600 m^3/d. The facilities included in Figure 4.12 were selected based on the level of treatment they provide (secondary treatment), the availability of the financial information concerning their construction, as well as their size (large urban facilities were left out because they do not reflect the situation of the rural study area). The Long Sault WWTP capital unit cost is significantly higher than the model's prediction. This is likely because at this facility, the sludge is anaerobically treated and the disinfection process is ultraviolet disinfection rather than chlorination. The task of collecting this information was complicated by the fact that wastewater treatment facilities costs that were available were often found for expansions or upgrades rather than for construction of new facilities. In the case of expansion and upgrade, the cost data cannot be compared to the model's result since a significant portion of the total facility cost (land, service buildings, etc.) is not included in the project cost.

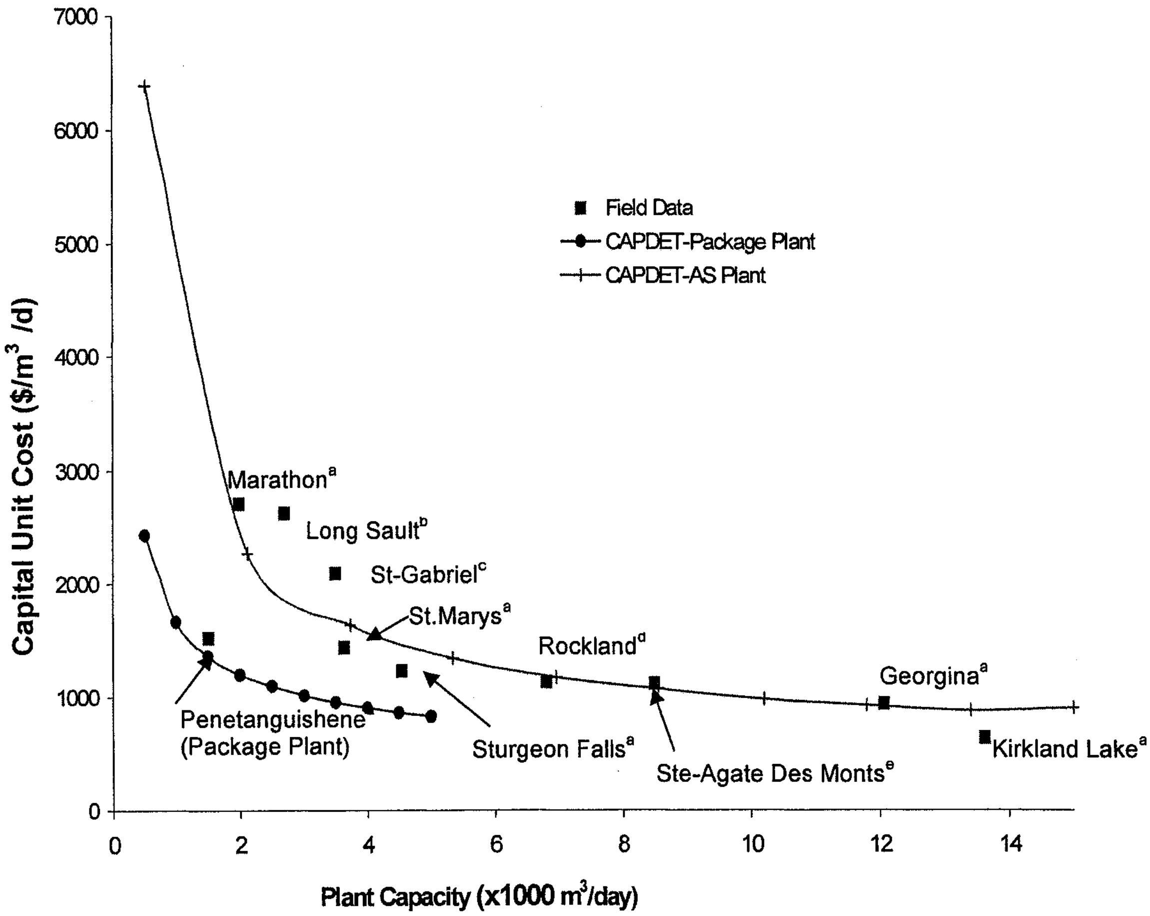


Figure 4.12 Mechanized wastewater treatment capital cost variations with plant capacity

[a] Source: Wright et al., 1988.
[b] Source: Industry Canada, 2004.
[c] Source: Turseault, 2004.
[d] Source: Rousselle, 2004.
[e] Source: Turseault, 2004.

From Figure 4.12, the cost of building a plant having a capacity of 15 000 m^3/d should be approximately 900 $\$/m^3/d$ capacity. For a smaller community, such as Marathon (with a capacity of 1 990 m^3/d), the capital costs for each cubic meter of wastewater treated could be as high as 2 700 $\$/m^3/d$ capacity. Figure 4.12 and previously presented Figures 4.10

and 4.11, show that a package treatment plant offers a more economical alternative for small flows. One would expect to obtain a trade-off point between the package plant and the conventional activated sludge treatment plant (i.e., a point where it is no longer economical to use a package plant as opposed to a conventional plant). In practice, although package plants are available in capacities up to 3 800 m^3/d, they are used most commonly for wastewater flows in the range from 38 to 950 m^3/d (Metcalf & Eddy, 1991). However, CAPDET does not limit the input flow size for package plants and will give estimates, which are lower than estimates for conventional plants, for flows as high as 15 000 m^3/d. For communities with flows in excess of 3 800 m^3/d, package plants should not be considered.

For most communities within the study area (with capacities ranging from 302 to 6818 m^3/d) that are currently using lagoon systems, the package plant option probably represents the best alternative to lagoon systems, assuming that the community has sufficient funding to initiate this improvement. The Township of Alfred, for example, charges an annual tax of $196.82 per household for sewage treatment (this also covers the maintenance of the collection system) (Gélinas, 2004). Using CAPDET's present worth (with a 5% interest rate) output value for a package plant of the same capacity as the Alfred lagoon (1 072 m^3/d), the annual tax per household for treating the sewage would be approximately $425.00 (collection system maintenance not included), over a 30 year period. The increase in annual costs for costumers is more than double, but these numbers represent a complete user-pay scenario. In the case of provincial government funding, the resulting annual increase of having a mechanized plant could be less dramatic. The decision of choosing to switch to a mechanized plant should depend on the receiving water vulnerability and the possibilities of upgrading the lagoon system for improved effluent quality. In the case of Alexandria (with a current lagoon capacity of 6 818 m^3/d), a conventional treatment plant would have to be built on-site if such a capacity is to be treated by the mechanized plant.

The high unit cost of treatment for a smaller community (even in the case of more economical wastewater treatment package plants), makes it difficult to justify the replacement of a lagoon by a mechanized plant. Nevertheless, a solution that will eventually lead to higher form of treatment should be sought. Solutions towards lagoon treatment upgrade such as the addition of intermittent sand filters before discharge of the effluent (see Section 5.3.2) or wastewater reuse in irrigation could be an alternative in solving effluent quality problems.

It should be pointed out at the outset that any cost estimation techniques at preliminary stages of design may not yield a precise estimate for any given plant. Not only do costs depend upon the particular plant design characteristics, but also on such factors as current and projected labor costs, attitude of proposed contractors regarding their need for work at the time of construction bidding, availability of materials, local conditions, climate and seasonal factors, length of the construction period, and many other variables that affect the actual construction costs. Thus caution must be exercised when utilizing any construction cost estimation techniques (Wright et al., 1988).

CHAPTER 5. DISCUSSION

The following discussion will be made in terms of the results presented in Section 4 in association with potential climate change impacts. Concerns raised in present conditions are extrapolated to speculate on the potential impacts of more intense weather events (more frequent greater precipitation events, more frequent and more severe droughts). This section also presents discussions on potential technical solutions to some of the concerns raised.

5.1 Water Treatment Plants

5.1.1 Water Supply

In the near future, water sources such as the Ottawa and the St. Lawrence Rivers are not expected to suffer extreme decreases in water flows that could endanger their supplies to WTPs. Plants withdrawing water from smaller streams and lakes, such as the South Nation River and the Mill Pond, may have to look for a complementary and/or different source of water in order to supply their demand.

Plants withdrawing water from the South Nation River, although they have no reported problems regarding their water intakes during dry periods, could have to change the location of their intake because of more pronounced variations of water levels induced by climate change. It may be of interest to point out that the South Nation River has peak flows of over 1 000 m^3/s during the spring freshet, and decreases to less than 20 m^3/s during summer low flows (Crabbé and Robin, 2003). This variation in water flows will likely be exacerbated by an intensified hydrologic cycle such as predicted with climate change.

5.1.2 Management of water demand

5.1.2.1 Water pricing

In a context where the earth's hydrological cycle is intensified and water supplies become more vulnerable to variation in capacity and quality, water pricing represents a key management tool in planning and controlling the use of water. Not only may water pricing be used to alleviate temporary water shortages, it may also have the effect to avoid the need for increased water supply and treatment, to extend the time between facilities expansion and extend the ability of existing supplies and systems capacity to meet growing demand. For this reason, water pricing and its application were reviewed an analyzed.

Water pricing has been implemented in many communities around the world with varying pricing structures as well as varying customer responses. There are many approaches to charging for water consumption, these different approaches are called rate structures and may be composed of fixed and variable fees charged for the supply of water. Fixed fees are independent of use levels and are typically in the form of service charges assessed each billing period regardless of the quantity consumed. Variable fees (rate per unit, often called a consumption charge) are based on the amount of water a consumer uses and are only possible if the community's distribution system is equipped with water metering. Within the study area, water distribution systems are mostly metered. Some communities have only the industries and businesses metered at present time. However, when discussing planning with regional system's managers of the study area, the trend seemed to be towards the complete metering of the systems.

Four general types of rate structure are predominantly employed by municipal water utilities: (1) a flat rate; (2) declining rates (the greater the quantity used the lower the rate); (3) inclining rates (the greater the quantity used the higher the rate); and (4) a constant rate (the same rate for each unit consumed) (Michelson et al., 1998; Loudon and Fortin, 1996). Figure 5.1 shows examples of flat rate, constant rate, and inclining block rate structures. Using a flat rate of \$17.50/month, which is the flat rate charged in Alfred-Lefaivre, the cost per cubic meter of water used decreases dramatically as the consumption increases (note that in Figure 5.1, the graph was truncated at \$2.50/ m^3, the maximum unit cost per m^3 in this case would be \$17.50 with a consumption of 1 m^3). Using the constant rate pricing structure, the cost for a cubic meter of water is constant, such as the \$0.45/m^3 constant rate shown in Figure 5.1, independently of the amount of water used. In the inclining block rate pricing structure, a constant rate is used for a given number of cubic meters of consumption and for additional cubic meters a higher (constant) rate applies. The inclining block rate structure shown in Figure 5.1 has a rate of \$0.25/m^3 for the first 20 m^3 and increases to \$0.65/m^3 for additional volumes. prices apply to different ranges of water consumed.

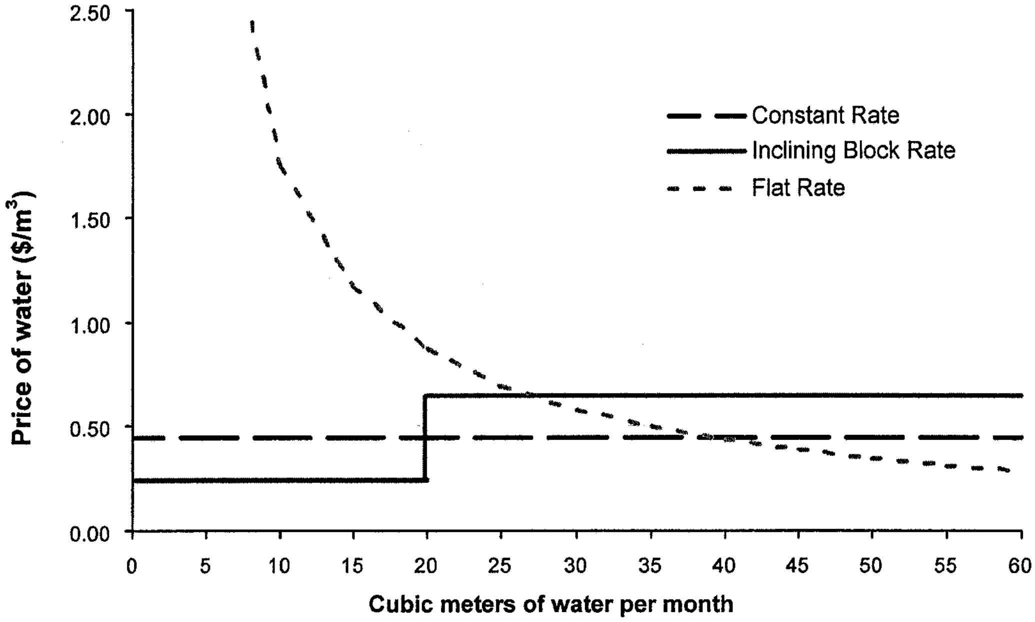


Figure 5.1 Example of constant and inclining block rate structures

Water rate structures across the study area vary from a flat rate with no metering, to a flat rate for a base amount plus charges for every cubic meter exceeding this base amount, to a fixed charge plus a unit cost for every cubic meter of water used. For example, in Alfred-Lefaivre in 2002 there was a flat rate of $210.00 per year per dwelling. In Plantagenet, there was a flat rate of $37.50 for 3 months of consumption plus a unit charge of $1.73 for every cubic meter used. Casselman charges a flat rate, which varies from $17.00 to $108.80 depending on the type of residence, plus a unit charge of $0.85 for every cubic meter used. Alexandria charges a flat rate of $16.50/month for the first 15 cubic meters and an extra $0.45 for each additional cubic meter used. It should be noted that at the Rockland plant, the rate structure at the moment of the survey consisted of a fixed annual charge of $70.00 per household, plus a $0.60 charge for every cubic meter of water consumed, nevertheless, this community as reported a pronounced increase in water demand during summer. In some communities, only industries and businesses are metered, this is the case for Hawkesbury, Ingleside and Long Sault. Figure 5.2 shows the monthly consumer cost curve as a function of the volume of water used for Alexandria, Casselman and Plantagenet pricing schemes. For comparison purposes, it takes approximately 75 m^3 of water to fill a standard home in-ground pool (10 m long by 5 m wide). Assuming an average water consumption of 0.4 m^3/cap/d, an individual household of four persons would consume approximately 48 m^3/mo. At this level of consumption, Figure 5.2 indicates significantly different water charges depending on the community where this family resides. In Plantagenet, one would pay more than four times what it would cost in Alexandria for this average amount of water.

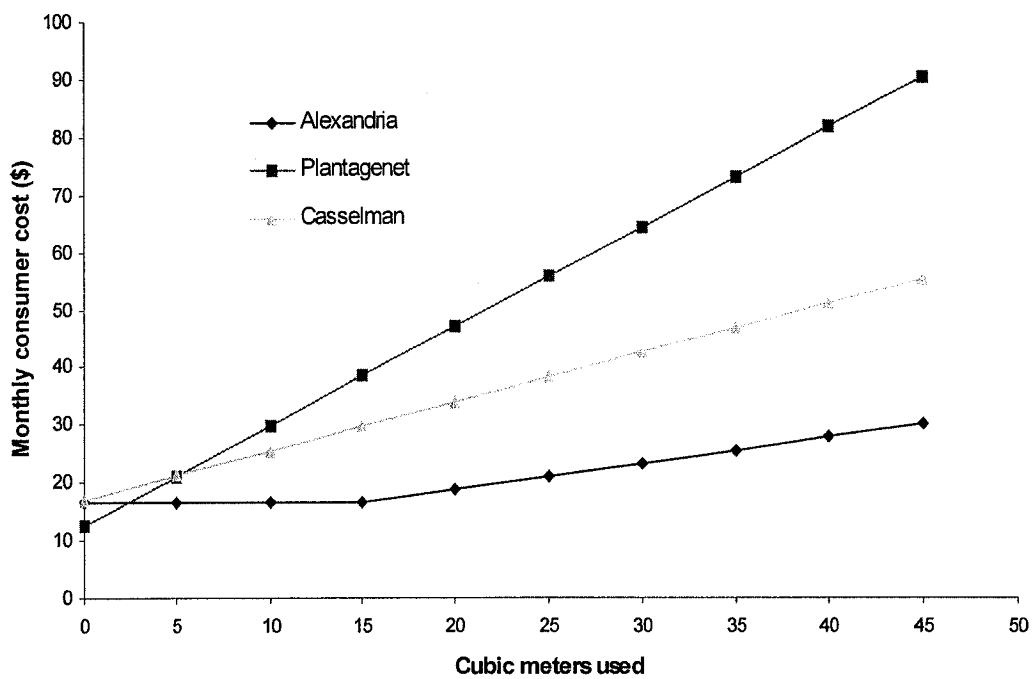


Figure 5.2 Monthly consumer cost for water in Alexandria, Plantagenet, and Casselman

Theoretically, declining rate and flat rate structures encourage higher water use because the cost of consuming each additional unit is less than the cost of the previous unit. Constant and inclining rate structures, in theory, are more conservation-oriented than declining or flat rate structures because consumers face the same or increasing prices for additional units of water consumed. In practice, studies have shown that price does have a significant and negative impact on water use, but water demand is very price inelastic (which means that you may have to increase water rates quite significantly before observing a change in water demand) (Espey et al., 1997; Michelson et al., 1998). The price elasticity of demand is a measure of consumer responsiveness of changes in the quantity of water consumed with changes in prices. Price elasticity is given in terms of the percentage change in the quantity consumed with one percent change in the price of a good (% ΔQuantity/ 1.0 % ΔPrice). A negative price elasticity value indicates a decrease in consumption of the good. In Michelson et al. (1998) analysis, the highest elasticity estimate was for summer use (approximately –0.20). With this degree of responsiveness, water utilities could double their water rates and expect only a 20% decrease in water use during the peak season.

Water consumers appear to be responding to a combination of marginal and average prices. This mixed consumer response is partly a result of the service charges used in most current rate structures. The use of fixed service charges with constant or block rate structures results in declining average prices as consumption increases. Figure 5.3 shows the average and marginal prices with a fixed charge of $8.00/month, plus a constant charge of $1.50/m^3 for every cubic meter of water used. The average unit cost of water is highest for the first cubic meter consumed, and as the consumption increases, the unit average cost decreases towards the actual marginal unit cost. The municipality of Alexandria, which has implemented such a rate structure, has observed a 30% reduction in water demand since the implementation of this water pricing system. Considering this important decrease in water demand, it seems that the population within the study area responds more positively to water pricing than what has been reported in the literature.

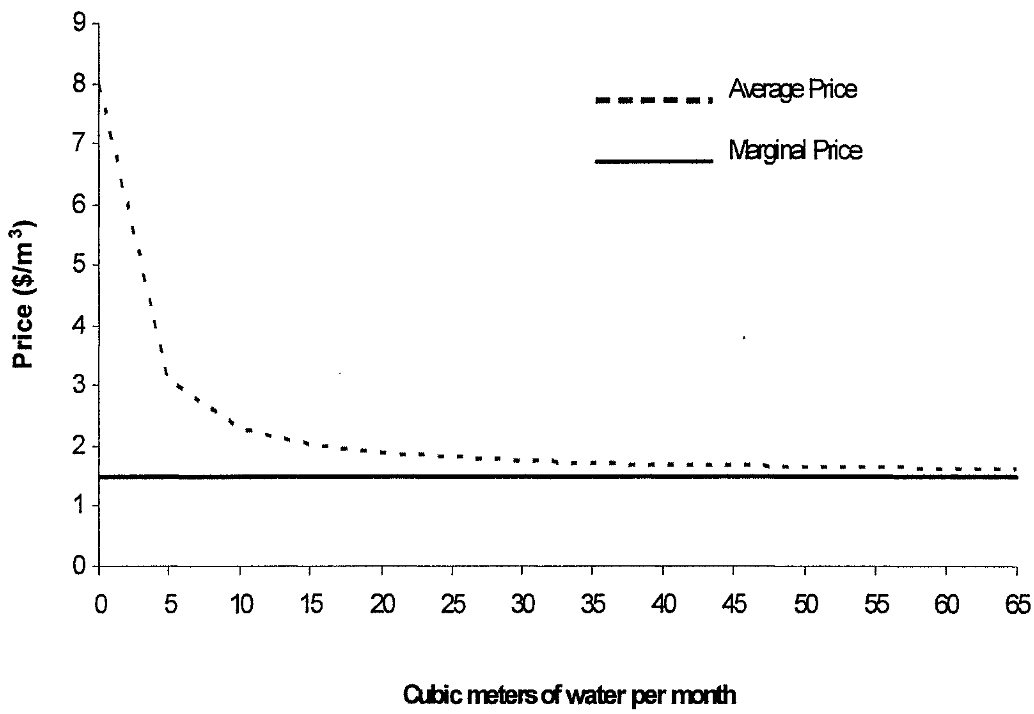


Figure 5.3 Average and marginal prices with constant rate and service charge

In 1996, approximately 36% of Ontario's serviced population was charged for municipal water services using a declining block rate structure, 28% of the population was charged using a constant rate structure and very few municipalities were using increasing block rates (Eaton, 1996). As per Eaton (1996) and also as observed during this study, the rates charged for water and wastewater services within Ontario vary dramatically. Prices are set by individual municipalities and seem to depend mostly on acceptance by local ratepayers and competition with other municipalities.

In summary, water pricing programs may be an effective way to reduce peak water demand and consequently delay plants expansion. Previous studies (Eaton, 1996, Michelson et al., 1998) support that water pricing programs require special attention as to how they are implemented and that utilities interested in using price to encourage conservation should re-examine the incentives provided by their structures and focus on reducing or eliminating the fixed charge component or incorporate it into the rate structure in a different form. Results within the study area however, seem to demonstrate that an important decrease in water demand (approximately 30%) may be reached with different rate structures, including rate structures with a fixed charge component. Although it appears that, within the study area, the water pricing rate structure does not have a major impact water demand decrease. A thorough analysis of water demand reduction after metering and the introduction of water pricing would need to be performed for each municipality of the study area in order to confirm which rate structure is the most effective.

Finally, it may be worth mentioning that water conservation is usually not the first objective pursued with water pricing. In a healthy sustainable system, the charges for water should cover the water production costs. In this approach, a portion of the production costs may be covered by a minimum fixed charge. This minimum charge could also include a fixed amount of water, say a conservative volume of water which would not allow for extra use such as pool filling, loan watering etc. Any amount of water exceeding the fixed base amount should be charged by volume. This idea is reflected in the policy of the American Water Works Association (AWWA) which states that every water utility should receive sufficient revenues from water service and user charges to enable it to finance all operating and capital costs (Loudon and Fortin, 1996).

5.1.2.2 Other options for management of water demand

Water restrictions may affect some usages such as lawn watering and street washing, which are mostly responsible for increased water demand during dry periods. Some municipalities (Hawkesbury, for example) have implemented water restrictions that have proven effective on water demand during dry periods.

Non-price conservation programs may be initiated in order to reduce water demand. Non-price water conservation programs include: information programs, promotion on water saving devices and practices such as the installation of drought tolerant grasses or the use of low-flow home devices (low flow shower heads, low-volume toilets) and distribution of plumbing retrofit devices.

5.1.3 Turbidity

Under present conditions, increases in turbidity from heavy rain and strong wind require the addition of chemicals for coagulation (alum) and disinfection. This was observed and reported for the Hawkesbury, Ingleside, Morrisburg and Long Sault water treatment facilities. A further increase in chemical dosages and the need for more frequent operational adjustments can be expected with more extreme weather events predicted with climate change. This may result in increased operational costs.

5.1.4 Taste and odor

Facilities where taste and odor episodes have been observed may experience an increased frequency of such episodes. Furthermore, taste and odor episodes may occur at facilities which have previously been free of such problems. Currently, only one plant in the study area (Glen Walter) has a GAC unit with the specific objective of taste and odor removal. With an increased occurrence of taste and odor episodes, other facilities may find it necessary to implement technologies aimed at taste and odor removal. Powdered activated carbon (PAC) may also be used for taste and odor removal, however, Quasim et al. (2000) suggest that PAC should be used for moderate and intermittent taste and odor episodes while GAC should be used for prolonged taste and odor problems. Note that in addition to carbon adsorption, disinfection technologies based on chemical oxidation such as chlorine, chloramines and ozone also remove taste and odor.

5.1.5 Cyanobacteria

During the survey conducted for this study, facilities managers and operators did not raise any concerns regarding cyanobacteria. However it is possible that cyanobacteria may become a water treatment issue as a result of climate change.

Schmidt et al. (2002) and Rositano et al. (2001) suggest that ozone is one of the best agents for the complete oxidation of toxins produced by cyanobacteria. The application of powdered activated carbon for toxin removal also appears to be effective (Schmidt et al., 2002). Lambert et al. (1996) studied the effect of GAC and PAC on the cyanobacterial toxin, microcystin-LR, and found that conventional treatment processes combined with activated carbon generally removed more than 80% of mycrocystin from raw water. Despite the high percent removal, residual mycrocystin concentrations of 0.1-0.5 μg/L were observed considering both GAC and PAC treatments.

5.1.6 Color

High color pulses can result from the additional transport of NOM with runoff after long periods without rain. With the intensification of weather events caused by climate change, variability in color might increase. At present, none of the treatment facilities within the study area as color removal as a main treatment objective. Conventional water treatment processes for other objectives, such as coagulation/sedimentation/filtration, oxidation and GAC adsorption are usually effective in removing color (Qasim et al., 2000). Should recurrent color problems arise at any of the facilities within the study area, it is likely that they can be managed through enhancement of the existing treatment processes.

5.2 Wastewater treatment plants

5.2.1 Capacity

Problems with regards to capacity are discussed in Section 4.2.2.1. Given that there are infiltration problems in many of the study area's collection systems, an increase in extreme rain event intensities will further swell the peak flows observed during such events. Municipalities that are currently practicing different forms of bypass during extreme flows will likely increase the quantity of bypassed wastewater during the more severe storms that are expected with climate change.

The main objective of temporary bypass of secondary treatment processes is to avoid loss of biomass because of hydraulically overloaded secondary clarifiers. This loss of biomass would result in inadequate performance until satisfactory biomass levels are recovered, a process that may take several days, a week or even longer to recover. Thus, temporary bypass results in short-term, somewhat deficient, performance as a means to avoid a longer and more severe loss of performance. The MOE guidelines for wastewater treatment are established in monthly averages. Temporary bypass of wastewater during rain events may therefore not necessarily result in a violation of the effluent criteria. However, during discharge of this partially treated wastewater, effluent criteria are likely not being met.

One solution to reduce or avoid bypass of wastewater during rain events may be the addition of equalization capacity at the head of an existing WWTP. Equalization capacity may represent an alternative to plant expansion, as treatment units do not have to be modified. With equalization capacity, peak flows are temporarily stored in an equalization basin and later redirected to the treatment process in a more uniform, lower flow. During the equalization capacity design process, one has to determine over what period of time flow equalization has to be provided, and the longer the period of time, the greater the equalization capacity is needed. Wastewater inflow variations may occur within a given day, from day to day, from week to week, and even longer periods of time. In practice, flow equalization has been mostly applied to regulate flow volumes for daily flow variations in sewer system. The flow equalization volume is usually determined using the cumulative mass curve method (Metcalf and Eddy, 1991; Stahre and Urbonas, 1990), which is based on inflow measurements. At the Hawkesbury wastewater treatment facility, equalization capacity was at the design stage during the survey performed for this study. The objective of the equalization capacity was to handle flows resulting from rain events which created the need for frequent bypass of partly treated wastewater (Guertin, 2002).

Stahre and Urbonas (1990) studied possible applications for equalization capacity and they concluded that because of the large storage volumes needed, it would be difficult to achieve complete flow equalization or to control the flows resulting from large storms or snow melt runoff. However, facilities where the need to perform bypass is frequent may benefit from a certain equalization capacity. Such equalization capacity may not be designed to handle peaks resulting from storm or spring snow melt, but they may equalize flows from rain events or wet periods of lesser extent which, in the absence of equalization capacity, would result in bypass of partially treated wastewater. A case by case analysis is necessary in order to determine if building equalization capacity represents a beneficial and feasible alternative for a given facility.

For discussion purposes, a preliminary analysis of the feasibility of flow equalization was prepared for the L'Orignal wastewater treatment facility. This is a small WWTP with a capacity of 955 m^3/day which is highly affected by snow melt, rain water inflow and infiltration. It is used here as an example of the potential application of equalization capacity to handle flows resulting from snowmelt and rainfalls. Wastewater inflows at the L'Orignal facility for year 1998 are presented in Table 5.1.

Table 5.1 **Wastewater flows at the L'Orignal treatment facility** (year 1998, adapted from OCWA database, 1998)

	Total Flow (m^3)	Average Day Flow (m^3)	Max Day Flow (m^3)
Jan	14 847	479	742
Feb	20 541	734	2 041
Mar	50 938	1 643	3310
Apr	31 169	1 039	2890
May	9 761	887	1 622
Jun	28 636	955	1 122
Jul	16 127	520	766
Aug	13 992	451	632
Sep	13 577	453	838
Oct	15 045	485	759
Nov	16 142	538	688
Dec	21 418	691	1 765

During peak flow periods (March and April), bypass of partially treated wastewater is practiced, sometimes to a ratio of 3:1 effluent to bypass. During the remainder of the year, the L'Orignal facility operates adequately and does not practice any form of bypass. In this particular case, the seasonal peak flows causing bypass are relatively high and they occur over a long period of time. Based on the cumulative mass curve method, the storage volume needed to avoid bypass during spring for this facility would be approximately 25 000 m^3. The construction cost for a 25 000 m^3 concrete rectangular tank (above ground with open top) would be approximately 555 000$. This cost does not include costs for equipment (such as mixing equipment, pumping equipment and piping) that may be necessary to operate the equalization basin. For comparison purposes, Section 5.3.4.4 of this work presents capital costs for construction of various sizes of WWTPs. The costs presented in Section 5.3.4.4 were developed from field data as well as from CAPDET Works 2.0 (Hydromantis, Hamilton. ON). According to these costs, construction of a package WWTP with a capacity of 2000 m^3/d would cost approximately \$1 300/m^3/d (\$2 600 000 total) in capital cost only. In the L'Orignal facility case, building equalization capacity would appear to be an economically sound option to avoid bypass of partly treated wastewater.

In situations where equalization capacity would not be economically or practically feasible (for example when the equalization volume needed is too large relative to the size of the plant), a municipality may focus on efforts of less important magnitude and which can be realized progressively towards reducing inflow and infiltration problems into the sewer system. In fact, the high degree of infiltration on the L'Orignal sewer system has been a concern for the regional decision makers and rehabilitation work on the sewer system was initiated in 2000 (Wilkinson, 2002).

It would be of interest to analyze the quantity and the frequency at which different wastewater facilities bypass partially treated wastewater. Based on the ratio of bypassed wastewater and frequency of bypasses, some facilities could be targeted for application of equalization capacity. During this study, the author attempted to analyze the pollutant loadings as well as the volume of partially treated wastewater that is bypassed to water courses during heavy rain events. Although some ratios (treated water/partly treated water) were obtained for certain facilities that do practice bypass during heavy rain events, no records on loadings or volume were obtained from the facilities. Wastewater discharge reports for years 1973, 1975, 1988, 1989, and 1995 to 2000 were consulted but no record on bypass of partly treated wastewater were encountered.

5.2.2 Impact on receiving waters

As discussed in Sections 4.2.2 and 5.2.1, climatic events where not observed to perturb wastewater treatment itself. The difficulty with an intensified hydrologic cycle may rather be observed on the receiving streams where the treated wastewater is discharged. During longer dry periods and consequent lower streamflows, the dilution capacity of streams is expected to decrease. Contaminants in wastewater effluents will therefore have a greater impact on the receiving waters. In such a context, it will become even more important to meet effluent standards. Currently, phosphorus and ammonia standards are not consistently met at certain locations within the study area. If precautions are not taken to eliminate these violations, they will likely have a greater impact on the receiving waters in the future. Furthermore, when analysis is performed in the process of issuing new C of A's, the outcome may be the application of more stringent criteria as streamflows are predicted to present higher variability, therefore higher vulnerability to pollutants absorption.

The case of the Vankleek Hill WWTP is an example of the impact a stream's low dilution capacity may have on the C of A of a facility. The Vankleek Hill plant (which consists of a rotating biological contactor followed by a lagoon system) discharges its treated wastewater into the Little Rideau Creek, a relatively small stream. For such a small receiving body of water, which has a small dilution capacity, treatment requirements are typically more stringent (the facility's C of A dictates the requirements it must comply with). The Vankleek Hill WWTP has an effluent requirement for ammonia-N of 1.6 mg/L in spring and 1.7 mg/L in fall. As a comparison, most WWTPs do not have ammonia criteria to comply with.

5.3 Lagoon systems

5.3.1 Capacity

Given that infiltration problems are extensive in the study area's collection systems, an increase in extreme rain event intensities will further swell the peak flows observed during such events. This should not cause stress on lagoon systems practicing annual or seasonal discharge, but systems practicing continuous discharge, such as the Alexandria and the Morrisburg lagoons, would likely see their effluent quality affected as a result of shorter hydraulic retention times. In such cases, change in climate towards more intense extreme flows will create the need for a greater wastewater treatment capacity, improved treatment, and/or equalization capacity.

5.3.2 Impact on receiving waters

As discussed in Section 5.2.2 with respect to mechanical WWTPs, it is expected that receiving waters will become more vulnerable to wastewater discharges as a result of loss of dilution capacity during low streamflows. This potential problem is also a concern with respect to lagoon systems, and may be exacerbated by specific characteristics of lagoon systems.

Performance problems observed in lagoon systems during dry periods are likely to be exacerbated during longer dry spells. Such performance problems were observed at the Winchester lagoon where the applicable 2.5 mg/L ammonia criteria was exceeded during a dry year (2002); the absence of rainwater dilution as well as high evaporation could have had for effect to "concentrate" the lagoon content and produce an effluent rich in ammonia. High SS from algae is also a problem that could arise from longer dry periods and warmer temperature as more stagnant conditions and warmer temperatures favor the growth of certain types of algae (Pick, 2002). Detailed investigations should be undertaken to identify the necessary corrective actions.

In the event of warmer winters (with less snow accumulation) and/or low spring precipitations, algal blooming could become a greater concern for spring lagoon discharges. Low water levels in lagoons, resulting from low precipitation and increased evapotranspiration (as predicted with a dry and warm climate scenario) will cause the delay of spring discharge and could foster greater algal growth within the lagoon. The presence of high quantities of algae could increase the effluent's SS to non-acceptable levels. Fall discharges could also suffer increased SS from the presence of algae after drier and warmer summers. Stringent effluent quality requirements for nutrients (N and P) may be of concern when using lagoon systems as N and P removals greater than 70 and 50%, respectively, can be difficult to achieve, especially at temperatures below 20°C

(Mara, 1996). Evans et al. (1993) state that improved environmental effluent quality standards since the introduction of the lagoons has resulted in many of these being unable to achieve proper effluent quality.

The Municipality of Alexandria has had concerns with its lagoon system effluent ammonia levels and is currently investigating for an efficient form of treatment for ammonia in lagoon effluents. Ammonia criteria, where applicable, are likely to be more frequently exceeded in a warmer and drier climate as increased evaporation and lower degree of sewer infiltration could concentrate the ammonia in the lagoon and its effluent during drought periods. Other factors that affect nitrification rates, including bacterial residence times, dissolved oxygen levels and temperature could even further increase ammonia concentration in lagoons; the net result of the different parameters on ammonia concentration is however not certain.

As discussed in Section 5.2.2, the difficulty with an intensified hydrologic cycle may rather be observed on the receiving streams where the treated wastewater is discharged. During longer dry periods and consequent lower streamflows, the dilution capacity of streams is expected to decrease. Contaminants in wastewater effluents will therefore have a greater impact on the receiving waters. In such a context, it will become even more important to meet effluent standards. Failure to meet phosphorus and ammonia standards will likely have a greater impact on the receiving waters in the future. Furthermore, when analysis is performed in the process of issuing new C of A's, the outcome may be the application of more stringent criteria as streamflows are predicted to present higher variability, therefore higher vulnerability to pollutants absorption.

5.3.2.1 Upgrade of lagoon effluent

P removal in lagoons can efficiently be achieved with the addition of alum. Within the study area, P removal is mandatory for all lagoon facilities and, on a general basis, the 1 mg/L TP criteria is being met (MOE, 2003c). Nitrogen removal, however, presents a greater challenge to lagoon facilities [lagoon effluent nitrogen concentrations are typically in the range of 15 to 20 mg/L (Metcalf & Eddy, 1991)] as there are only few technologies for lagoon upgrades that provide satisfactory ammonia removal (where applicable). Furthermore, at the MOE, there have been discussions about applying an "end of pipe" unionized ammonia (NH_3) criteria of 0.01 mg/L in Ontario (Crolla, 2004 and Manoharan, 2004). At present time, the ammonia guideline (1 mg/L) is in terms of total ammonia (NH_4^+ + NH_3), but the unionized ammonia (NH_3) is the pollutant that is actually toxic to fish. Lagoon systems with aeration can reach effluent total ammonia concentrations of 1 to 3 mg/L, but in most cases reaching an effluent unionized-ammonia criteria of 0.01 mg/L may not be achievable (Crolla, 2004). The Canadian environmental quality guideline for in-stream unionized ammonia is 0.019 mg/L. No limits are set in drinking water standards (Government of Canada, 2002).

A lagoon enhancement process has been accepted by the Ontario Ministry of the Environment as the Best Available Technology (BAT) for the removal of ammonia from lagoons effluent (Manoharan, 2004; Willcocks, 2000; and Evans et al., 1993). In Ontario, this process is known generically as the New Hamburg process as it was first applied in the early 1980s in New Hamburg, ON. This process uses intermittent sand filters to enhance effluent quality from facultative lagoons. The intermittent sand filter exposes lagoon effluent to open air to provide oxygen and to coarse sand media to provide a growth site for bacteria which promotes the conversion of ammonia in the effluent to nitrate through nitrification. Exposure to oxygen also removes the H_2S (Willcocks, 2000). The media also acts as a physical barrier to the migration of effluent solids into the final effluent (Evans et al., 1993). This enhancement may allow continuous effluent discharge for an extended period instead of the twice-yearly seasonal discharge, which requires a 180 day retention period. The limiting factor of the process is that the nitrification treatment can not be maintained during the coldest winter months when the ambient liquid temperatures fall to less than 4°C. This is the lowest viable temperature for maintaining nitrification. Depending on the location in Ontario, the original treatment and storage requirement of 180 d may be reduced to a three or four month storage period, effectively increasing the capacity of the same lagoon volume by 33-50% (Willcocks, 2000).

If land is available, the option of adding a constructed wetland after the lagoon system may represent another alternative to nutrient removal. Nichols (1983) reviewed the dynamics of nutrient removal in wetlands from Florida to Canada's Northwest Territories. He found that, in general, phosphorus and nitrogen can be efficiently removed from wastewater if large wetland areas are available and populations are low (on the average approximately 1 ha of wetland is required to remove 50% of the N and P from the wastewater produced by 60 people). At the MOE, constructed wetlands are studied on a case-by-case basis and their approval may be rather long and complex (Crolla, 2004 and Manoharan, 2004). In order for the MOE to consider the possibility of approving a constructed wetland, there has to be 3 years of data on the constructed wetland performance. At the time of the study, such a constructed wetland had been at the pilot stage for 2 years in Alfred, ON. This project is an initiative of Alfred College and is used as a polishing step after lagoon treatment (as such, the lagoon's effluent is the wetland influent). With the Alfred wetland, it is possible to reach a total ammonia level of 0.1 mg/L, however the lagoon's effluent total ammonia level is quite low (0.6 mg/L) (Crolla, 2004). Because of the initially low ammonia levels entering the wetland, Alfred's constructed wetland results may not be necessarily applicable to other systems where influent ammonia levels are higher. In certain situations, the addition of a constructed wetland to polish lagoon effluents could provide solutions to effluent quality problems, but the extensive period and efforts necessary for testing and approval of the process may discourage one to choose this option.

Available technologies for the removal of ammonia from lagoon effluents are numerous, but the only technology that has been proven (i.e., used successfully long enough, with sufficient data to support its efficiency) is intermittent sand filtration. This technology can only be used on seasonal discharge facilities, as it cannot be operational during winter months. Until other technologies have been sufficiently established (performance and economy) for continuous discharge lagoon systems, the solution for ammonia removal will most probably be the upgrade to mechanized technology (Manoharan, 2004).

5.3.2.2 Upgrade of lagoon capacity

Upgrade of lagoon capacity is a potential alternative for coping with the problem of hydraulic overloading with resulting degraded effluent quality. However, upgrade of lagoon capacity will not resolve problems associated with typical lagoon effluent quality, such as ammonia and algae.

5.3.2.3 Upgrade to mechanized wastewater treatment plant

As described in Section 4.3, an upgrade from a lagoon to a mechanized WWTP is a potential alternative for solving the various deficiencies that are inherent in lagoon systems. However, a mechanized WWTP represents a significant capital cost and increased operating cost as compared to a lagoon system. Consequently, decision-makers will have to balance the higher performance of a mechanized treatment system against the higher cost. To assist with such decision-making, the existing CAPDET software has been adapted to the specific conditions of the study area. Decision-makers may consult the data presented in Section 4.3 to obtain a preliminary indication of costs for a typical small mechanized WWTP in the study area. For a specific case, the methodology presented in Section 4.3 can be applied to obtain a more accurate cost estimation.

Previous studies have identified the South Nation watershed as being highly eutrophic. It is known that in this watershed, 90% of the nutrient load comes from non-point sources (NPS) rather than from wastewater treatment effluents (Crabbé and Robin, 2003). So, while it would be desirable to replace lagoon systems with tertiary treatment plants because of their superior effluent quality, this would not significantly reduce the eutrophication problems within the watershed. However, switching to a mechanized treatment (secondary or tertiary) plant would reduce algae, thus reducing algae (taste and odor) problems at downstream WTPs. In addition, having continuous effluent discharge, as with mechanized plants, would lead to a small stream flow augmentation during dry periods, which could benefit aquatic life.

5.4 Water reuse

Water reuse sites are often located in arid and semi-arid areas because of water scarcity and the need for alternative sources of water. However, an increasing number of wastewater reuse projects are being implemented in humid regions for water pollution abatement as well as for water supply purposes (Metcalf and Eddy, 1991). Reuse of municipal wastewater has two main benefits: (1) it eliminates adverse health or environmental impacts of discharging the effluent into surface water, and (2) it provides for beneficial use of the effluent as a water source.

Currently, water reuse has not been implemented in the study area. However, the benefits of water reuse may be of interest in a future context where water sources are expected to become more scarce and vulnerable.

To date, the major areas for water reuse have been the use of reclaimed wastewater for irrigation, cooling towers, and groundwater recharge. In the planning and implementation of water reclamation and reuse, the intended water reuse applications dictate the extent of wastewater treatment required and the quality of the finished water. The simplest treatment systems involve solid/liquid separation processes and disinfection whereas more complex treatment systems involve combinations of physical, chemical, and biological processes employing multiple barrier treatment approaches for contaminant removal. The most sophisticated treatment systems are associated with production of potable water from reclaimed wastewater.

5.4.1 Water reuse for irrigation

Indications that wastewater was applied as a water source for agricultural irrigation extend back approximately 5 000 years. In the United States, irrigation of lawns and gardens with reclaimed wastewater was practiced in Arizona and California as early as beginning of the 20^{th} century (Asano, 1998). Where reclaimed wastewater is used for irrigation, biological agents including bacteria pathogens, helminths, protozoa, and viruses pose the greatest health risks (Bouwer, 1991; Metcalf and Eddy, 1991). No Canadian guidelines for wastewater reuse are established, but some provinces in Canada (including, British Columbia, Saskatchewan, and Alberta) provide guidelines for conveying reclaimed water to intended customers, these guidelines are based on level of treatment, intended use, and operational practices. The U.S. Environmental Protection Agency (EPA) published guidelines in 1992 that are intended to provide guidance to utilities and regulatory agencies in states where standards do not exist. The World Health Organization (WHO) also published recommended guidelines for wastewater use in agriculture and aquaculture (WHO, 1996). Treatment requirements for irrigation from both organizations are presented in Table 5.2.

Table 5.2 WHO and USEPA wastewater treatment requirements for different irrigation applications (adapted from Asano and Levine, 1996)

Organization	Reuse conditions	Fecal coliforms or Total[a] Coliforms	Wastewater treatment requirements
WHO	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	< 1 000/100 mL	A series of stabilization ponds or equivalent treatment
WHO	Landscape irrigation where there is public access, such as hotels	< 200/100 mL	Secondary treatment followed by filtration and disinfection
California	Spray and surface irrigation of food crops, high exposure landscape irrigation such as parks	< 2.2/100 mL	Secondary treatment followed by filtration and disinfection
WHO	Irrigation of cereal crops , industrial crops, fodder crops, pasture and trees	No standard recommended	Stabilization ponds with 8-10 day retention or removal equivalent
California	Irrigation of pasture for milking animals, landscape impoundment	< 23/100 mL	Secondary treatment followed by disinfection

[a] California Wastewater Reclamation Criteria is expressed as the median number of total coliforms per 100 mL, as determined from bacteriological results of the last 7 days for which analyses have been completed.

For water reuse applications that have potential for significant human exposure; e.g., spray irrigation of food crops eaten uncooked, parks and playgrounds, and unrestricted recreational impoundments where swimming may take place, it is important that the reclaimed water is virtually virus-free. Two studies performed in the U.S., The Pomona Virus Study (Parkhurst, 1977) and the Monterey Wastewater Reclamation Study for Agriculture (MWRSA) (Asano, 1998) demonstrated conclusively that virtually pathogen-free effluents could be produced from municipal wastewater via tertiary treatment and extended disinfection with chlorine. A major result of these studies was the scientific demonstration that even food crops that are consumed uncooked could be successfully irrigated with reclaimed municipal wastewater without adverse health effects. After five years of field experimentation on a perennial crop of artichokes along with rotating annual crops of celery, broccoli, lettuce, and cauliflower, the Monterey Wastewater Reclamation Study for Agriculture also demonstrated a significantly higher crop yield for crops irrigated with reclaimed wastewater than yields produced from irrigation using local well water. The experiments were made using reclaimed wastewater from two municipal tertiary wastewater treatment systems including coagulation (using alum or anionic polymer), sedimentation, filtration with granular medium, and disinfection (using chlorine or ozone).

Within the study area, irrigation of agricultural land as well as golf courses from WWTPs could present a sound solution to nutrient discharge problems into surface waters while providing an opportunity for a reduction in the use of fertilizers. A study performed on sorghum, maize and sunflower crops in Portugal (Asano, 1998) reports financial values of the fertilizers savings as high as $US 198 per hectare. Table 5.3 presents the savings in commercial fertilizers resulting from wastewater irrigation for the three crops studied in Portugal. The primary and secondary effluents were taken from a high-rate trickling filter plant. Nitrogen represents the most beneficial nutrient and the one most frequently present in the highest concentrations in reclaimed municipal wastewater. Feasibility for the use of reclaimed wastewater for irrigation would depend on many factors including proximity of wastewater source to reclaimed water application as well as quality of the reclaimed water. Some adjustments or addition to the actual wastewater treatment trains could be necessary (filtration and disinfection). Given that the region's water demand for golf courses and agriculture represent, respectively 4 and 18% (CH2M Hill, 2001) of the region's total water demand, use of reclaimed wastewater for these applications could significantly reduce the total region's water demand.

Table 5.3 Savings in commercial fertilizers resulting from wastewater irrigation (Asano, 1998)

		Primary and Secondary Effluents		Facultative Pond Effluent	
Crop	**Units**	**Kg/ha**	**US$/ha**	**Kg/ha**	**US$/ha**
Sorghum	N	140	109	140	109
	P_2O_5	50	34	n/a	n/a
	K_2O	120	55	60	27
Maize	N	155	121	155	121
	P_2O_5	40	42	n/a	n/a
	K_2O	60	27	27	14
Sorghum	N	65	50	65	50
	P_2O_5	30	54	n/a	n/a
	K_2O	15	14	15	14

5.4.2 Water reuse for groundwater recharge

Groundwater recharge with reclaimed wastewater is an approach to wastewater reuse that results in an increased capacity of groundwater supplies. Groundwater aquifers provide natural mechanisms for treatment and storage of reclaimed water. Purification is provided during flow of effluent through the soil of the unsaturated zone and in the aquifer. Pollutant removal mechanisms include volatilization, chemical or biological conversion reactions, precipitation of metals, and sorption within the soil matrix. Survival of pathogens that may be present in the input wastewater depends on soil and infiltration rates and aquifer conditions.

The major methods of water application for groundwater recharge include surface spreading and direct injection. Spreading basins capitalize on the purification capacity of the unsaturated zone and the aquifer. Common wastewater reclamation processes prior to recharge include primary and secondary wastewater treatment and tertiary granular-medium filtration followed by disinfection (Metcalf and Eddy, 1991). Direct subsurface recharge is achieved when water is injected directly into a groundwater aquifer. In direct injection, highly treated reclaimed wastewater is injected directly into the saturated groundwater zone, usually into confined aquifer. Direct injection requires water of much higher quality than surface spreading to control clogging in aquifer materials and prevent compromising the hydraulic capacity of the confined aquifer (Bouwer, 1991).

In Southern California, groundwater recharge is an increasingly important water resources management tool as previously imported water supplies are reallocated to meet the needs of other southwestern states and endangered species. Orange County Water District (OCWD) has practiced groundwater recharge by both direct injection and surface spreading for over 20 years (Asano, 1998). OCWD has implemented two unique recharge programs as part of its groundwater resources management plan. The first program is Water Factory 21 (WF-21), an advanced wastewater reclamation project that directly injects highly treated reclaimed water into coastal aquifers to prevent seawater intrusion. The facility produces up to 57 000 m^3/d of highly treated water for injection into coastal aquifers to prevent seawater intrusion into local groundwater supply. Since 1976, WF-21 has injected over 1.2×10^8 m^3 of highly treated reclaimed water into the aquifer system, creating a freshwater pressure ridge that hydraulically prevents seawater intrusion.

Injected water also flows inland and augments potable water supplies. The water source to the WF-21 advanced wastewater treatment facility is secondary effluent from an activated sludge WWTP. The WF-21 treatment train includes chemical clarification (with high lime dosage to achieve a pH of approximately 11.2), clarification, recarbonation (to reduce the pH from 11.2 to approximately 7.0), chlorination (to reduce algal growth), and multi-media (anthracite, silica sand, and garnet sand) filtration. During the process, over 99% of coliform bacteria are removed, and viruses are effectively inactivated by the high pH. The filter effluent turbidity averages 0.14 to 0.16 NTU. The filter effluent is split into two parallel flow streams that feed into the GAC or the reverse osmosis processes. Activated carbon removes 30 to 50% of the organics. The reverse osmosis system removes approximately 85 to 95% of the TDS and 81% of the TOC, resulting in a product water containing 140 mg/L TDS and less than 1.0 mg/L TOC. The effluent is finally pumped into a chlorine contact basin.

It was found that on a monthly basis, the Eastern Ontario's vulnerability to drought is extremely variable from one month to the next and from one geographic location to the next (Crabbé and Robin, 2003). In supply-vulnerable areas, artificial groundwater recharge could present a solution during periods of drought. Such applications have been used successfully by other municipalities in Ontario; for example, the Municipality of Waterloo, which draws its water entirely from groundwater (Crabbé and Robin, 2003). The use of groundwater recharge could also be a measure that would help mitigate current groundwater contamination by agriculture; results presented in Crabbé and Robin (2003) report that over half of the sampled wells within the study area were contaminated with coliform bacteria and approximately 7.4% tested positive for E. coli. Without proper measures, the situation is likely to deteriorate with climate change: increased demand on the deep groundwater system will increase the downward circulation of groundwater and consequently increase the deep aquifer vulnerability. The use of groundwater recharge with reclaimed wastewater could decrease the demand on the deep aquifer, minimizing the downward circulation of groundwater and the deep aquifer vulnerability to contamination.

Approximately two-thirds (63%) of the water demand in the study area is met from groundwater (CH2M-Hill, 2001). It is therefore extremely important that the use of reclaimed wastewater for groundwater recharge involves proper treatment as well as proper management in order not to further contaminate the supply.

5.5 Adaptation of water infrastructure to climate change

This study has identified a number of potential impacts of climate change on the water infrastructure of the study region. This finding compels a consideration of how the water infrastructure will adapt to these impacts. This question can be addressed through examination of the existing processes by which the water infrastructure adapts to changes such as population growth, changes in regulatory requirements, and the availability of new technologies. These processes of adaptation occur within a framework of a long-term design cycle, intermediate-term upgrade cycles and continual short-term adjustments.

The long term design cycle is approximately 15 to 25 years. This is the typical design lifetime of a water infrastructure facility. Consequently, the opportunity for major adaptations in response to climate change arises every 15 to 25 years.

The intermediate upgrade cycle is approximately 5 to 10 years; the length of this cycle is determined by the typical lifetimes of major components such as pumps.

The short term adjustments consist of the everyday measures that are implemented at a water infrastructure facility in response to short term changes in operating conditions. Examples of such measures include changes in chemical dosing, frequency of testing and addition of equipment.

This existing framework of adaptation should be adequate to cope with the impacts of climate change, particularly if these impacts are monitored and considered in the long term planning process.

The impacts of climate change will impose extra operating and capital costs ranging from increased chemical quantities to a major increase in capacity. In addition to increased costs, there will also be increased uncertainty regarding costs. Both the increased costs and the increased uncertainty must be taken into account in planning and budgeting.

CHAPTER 6. CONCLUSIONS

6.1 Critical climate change phenomena

Dry periods, heavy rain events, heavy spring runoff and increased temperatures are the critical climate change phenomena that are expected to have the greatest impact on the water infrastructure of the study area. The specific impacts on each component of the water infrastructure are described in the following sections.

6.2 Potential impacts on water treatment systems

6.2.1 Increased water demand during dry and hot weather

With the exception of Alexandria, all water treatment facilities investigated showed an increase in water demand during dry and hot weather. It can be expected that such increases in demand will be exacerbated as the frequency and severity of droughts increase.

One of the methods used to control increases in water demand is metering of water consumption. Most communities in the region meter a part of their water consumption, and this has been shown to be effective in reducing water demand. At the time of the study, municipalities that did not have metering exhibited interest in implementation of metering.

6.2.2 Reduced quantity of supply during dry periods

Climate change is expected to cause an increase in the frequency and severity of dry periods, exacerbating the scarcity of water for those communities already experiencing water shortages. Water supply from large rivers, such as the Ottawa and St. Lawrence Rivers, is not typically sensitive to dry periods. However, WTPs withdrawing water from smaller streams and lakes, such as the South Nation River and the Mill Pond, may have to consider either supplementary short term sources during dry periods or alternative long term sources which are less sensitive to dry periods.

6.2.3 Reduced quality of supply

Turbidity events typically occur during periods of heavy runoff, either spring runoff or storm runoff. It is expected that climate change will increase the intensity of spring runoff, and the intensity and frequency of storm runoff.

Taste and odor problems due to algal growth during spring and summer are an existing concern for at least five facilities in the study area. It is expected that this phenomenon will increase as a consequence of increased temperatures, increased evaporation rates and longer dry periods during the spring, summer and fall.

6.3 Potential impacts on mechanized wastewater treatment plants

6.3.1 Increased peak flows

Inflow and infiltration into the sewer system during spring runoff and rain events is a typical problem in the study area, resulting in high peak flows at wastewater treatment facilities. Currently, certain WWTPs in the study area use bypass as a method to cope with extreme peak flows. It is expected that climate change will increase the intensity of spring runoff, and the intensity and frequency of rain events. Consequently, it is likely that there will be an increase in the frequency of bypass events, and an increase in the volume of bypassed wastewater.

6.3.2 Reduced dilution capacity of receiving waters during periods of low streamflow

Intensification of the hydrologic cycle is an expected consequence of climate change. This implies an increased frequency and intensity of periods of low streamflow, and therefore a reduction in the dilution capacity of receiving waters, particularly small streams. This increased vulnerability may eventually be reflected in more stringent discharge criteria.

6.4 Potential impacts on lagoon wastewater treatment systems

6.4.1 Reduced hydraulic retention time

Extreme rain events and heavy spring runoff may affect the treatment efficiency of lagoon systems that practice continuous discharge. Such events will further swell the normal wastewater flow to several times the dry weather flow, likely causing incomplete treatment of the wastewater before discharge.

In the case of lagoon systems that discharge annually or seasonally, the volume of wastewater directed to the lagoon should not change significantly except during wet years or wet seasons. In such situations, the maximum capacity of the system could be exceeded, creating the need for discharge before complete treatment has occurred or before the period indicated on the facility's C of A.

6.4.2 Increased algae growth within the lagoon during dry periods and periods of higher temperatures

It is expected that climate change will result in increased frequency and intensity of dry periods and periods of higher temperatures. This will promote the growth of algae within wastewater treatment lagoons, due to higher temperatures and reduced mixing. Consequently, the quality of the effluent will be degraded and exceedances of discharge criteria may occur.

6.4.3 Increased impact on receiving waters

Climate change will result in reduced dilution capacity of receiving waters during periods of low streamflow. With lagoon systems, this problem is exacerbated due to the degradation of effluent quality during dry periods and periods of higher temperatures which are associated with periods of low streamflow. This may result in events of significant degradation of instream water quality. Such events may lead to pressure for conversion of lagoon systems to mechanized wastewater treatment systems. This issue is considered further in the following section.

6.5 Adaptation of water infrastructure

The impacts of climate change on the water infrastructure of the study region do not constitute a potential future crisis. Impacts will occur, but can be managed within the existing framework of a long term design cycle (15 to 25 years), intermediate term upgrade cycles (5 to 10 years) and continual short term adjustments, as discussed in Section 5.5.

The impacts of climate change will impose extra operating and capital costs ranging from increased chemical quantities to a major increase in capacity. In addition to increased costs, there will also be increased uncertainty regarding costs.

Conversion from a lagoon system to a mechanized WWTP is an example of an adaptation that may be driven, at least in part, by the impacts of climate change. This is an adaptation that will take place within the long term design cycle. Such a conversion would represent a major component of the cost of adaptation of the water infrastructure to climate change. The cost estimation methodology applied in this study, using the CAPDET software, provides a tool for decision making with respect to this major cost component.

CHAPTER 7. RECOMMENDATIONS

This chapter provides a set of specific recommendations with respect to the adaptation of individual components of the water infrastructure to climate change impacts, and concludes with general recommendations to enhance the overall efficiency of the adaptation process.

7.1 Water treatment systems

7.1.1 Water demand and supply

It is recommended that the linked problems of decreased supply and increased demand be addressed through management of water demand. Approaches for management of water demand include the following:

- Implementation of metering on the water distribution system;
- Application of non-price conservation programs such as water use restrictions during dry periods, information programs, promotion of water saving devices and practices such as the installation of drought tolerant grasses or the use of low-flow home devices (low flow shower heads, low-volume toilets).

Losses of water through leaks in the distribution system should be addressed through repairs and rehabilitation of the distribution system.

Permits to take water should be monitored and should be revenue generating. These revenues could be reinvested in water conservation and reuse. The Ministry of the Environment has already undertaken part of this work by preparing a draft regulation that lays out proposed amendments to the current regulation on permits to take water (MOE, 2003b). The proposed amendments will:

- Require new permit applicants to notify municipalities, conservation authorities, and adjacent landowners about proposed water takings;
- Require reporting of water use by permit holders; and
- Define potential impacts that will be considered when reviewing permit applications.

Water reuse should be considered for the irrigation of golf courses and agricultural land.

7.1.2 Treatment

It is recommended that water treatment managers and engineers be prepared for the following contingencies with respect to water treatment:

- Extra cost for turbidity removal chemicals, due to increased turbidity from more frequent storms;
- Possible need for treatment of taste and odor for WTPs that experience taste and odor episodes;
- Possible need for treatment of color for water treatment facilities that experience severe and consistent episodes of colored water.

7.2 Mechanized wastewater treatment plants

7.2.1 Increased peak flows

It is recommended that municipalities take measures to reduce rainwater infiltration into the collection system, particularly because of the more severe and frequent rain events expected with climate change, in order to minimize the need for increased capacity of mechanized WWTPs. Such measures include the following:

- Rehabilitation work on sewers that suffer high infiltration;
- Investigation and elimination of illegal connections to the sewer systems;
- Separation of combined sewers.

It is recommended that engineers involved in the design or upgrade of WWTPs consider measures to cope with the expected higher peak flows, including the following:

- Increase in design capacity to allow for the expected larger peak flows;
- Flow equalization should be considered as a measure for reduction of peak flows and as an alternative to increased design capacity.

7.3 Lagoon treatment systems

7.3.1 Reduced hydraulic retention time and impacts on receiving waters

For cases in which upgrade or expansion of a lagoon system is under consideration, it is recommended that the municipal authorities involved in this decision making process consider the alternative of conversion to a WWTP. A first approximation of the cost of such a conversion can be obtained from the cost curves presented in Section 4.3 of this study. The methodology presented in Section 4.3 can be applied to a specific case, in order to obtain a more accurate cost estimate. A final cost estimate would have to be based on a detailed engineering design.

For cases in which the conversion of a lagoon system to a mechanized treatment plant is not economically feasible, it is recommended that appropriate measures be taken to reduce the impact on receiving waters, such as the following:

- Addition of a polishing step such as an intermittent sand filter or a wetland system;
- Use of lagoon effluent for irrigation, rather than direct discharge to receiving waters.

7.4 Adaptation of water infrastructure

As discussed in Section 5.5, the impacts of climate change on the water infrastructure of the study region can be managed within the existing framework of a long term design cycle (15 to 25 years), intermediate term upgrade cycles (5 to 10 years) and continual short term adjustments. However this adaptation will involve increased operating and capital costs and increased uncertainty regarding costs. Therefore, it is recommended that the parties involved in the planning, design and operation of the water infrastructure take measures to improve the efficiency and cost effectiveness of the adaptation process. Such measures include the following:

- Consideration of the impacts of climate change in the long term planning and budgeting process;

- Application of appropriate technologies and practices which are aimed at preventing, mitigating, or reducing the negative impacts of climate change on the water infrastructure.

CHAPTER 8. REFERENCES

Akinremi, O.O., S.M. McGinn, and H.W. Cutforth, 1999. Precipitation trends on the Canadian Prairies. *Journal of Climate*. 12 (10), 2996-3003

Angel, J.R. and S.A. Isard, 1998. The frequency and intensity of Great Lake cyclones. *Journal of Climate*. 11(1), 61-71

Asano, T., 1998. Wastewater reclamation and reuse. Technomic Publishing Company, Inc., Lancaster, PA.

Asano, T. and A. D. Levine, 1996. Wastewater reclamation, recycling and reuse : past, present, and future. *Water Science and Technology*. 33 (10-11), 1-14.

Balmér, P. and B. Mattsson, 1994. Wastewater treatment plant operation costs. *Water Science and Technology*. 30(4), 7-15.

Boller, M., 1997. Small wastewater treatment plants-A challenge to wastewater engineers. *Water Science and Technology*. 35(6), 1-12

Bouwer, H., 1991. Role of groundwater recharge in treatment and storage of wastewater for reuse. *Water Science and Technology*. 24 (9), 295-302

Briand, J.F., Robillot, C., Quiblier-Llobéras, C., Humbert, J.F., Couté, A., and C. Bernard, 2002. Environmental context of Cylindrospermopsis raciborskii (Cyanobacteria) blooms in a shallow pond in France. *Water Research*. 36(13), 3183-3192.

Brière, F.G., 1997. Distribution et collecte des eaux. Édition de l'École Polytechnique de Montréal, Montréal, PQ.

Brittain, S.M., J. Wang, L. Babcock-Jackson, W.W. Carmichael, K.L. Rinehart and D.A. Culver, 2000. Isolation and characterization of Microcystins, cyclic hepatapeptide hepatotoxins from a Lake Erie strain of microcystis aeurginosa. *Journal of Great Lakes Research*. 26(3), 241-249.

Burhoe, D., 2003. University of Ottawa. Personal communication.

Carmichael, J.J., K.M. Strzepek, and B. Minarik, 1996: Impacts of climate change and seasonal variability on economic treatment costs: a case study of the Nitra River Basin, Slovakia. *International Journal of Water Resources Development*. 12, 209–227

CH2M-Hill Canada Limited, 2001. *Final report - Eastern Ontario water resources management study (EOWRMS)*. United Counties of Prescott & Russel, Stormont, Dundas, Glengarry, City of Ottawa.

Chemical Week Publishing, 2004. Economic indicators-Marshall & Swift Equipment Cost Index. *Chemical Engineering*. 111(3), 88.

Copp, J., 2004. Hydromantis. Personal communication.

Crabbé P. and M. Robin, 2003. *Institutional adaptation to climate change of water-related infrastructures in Eastern Ontario-Final report.* University of Ottawa. Ottawa, ON.

Creese, E.E. and J.E. Robinson, 1996. Urban water systems for sustainable development. *Canadian Water Resources Journal.* 21(3), 209-220.

Crites R. and G. Tchobanoglous, 1998. Small and decentralized wastewater management systems. McGraw-Hill, New York, NY.

Crolla, A., 2004. Alfred College. Personal communication.

Crowley, T.J., 2000. Causes of climate change over the last 1000 years. *Science.* 289 (5477), 270-277.

Cruise, J.F., A.S. Limaye, and N. Al Abed, 1999. Assessment of impacts of climate change on water quality in the southeastern United States. *Journal of the American Water Resources Association.* 35(6), 1539–1550

Dauta, A., 1982. Conditions de développement du phytoplankton.Étude comparative du comportement de huit espèces en culture. I. Détermination des paramètres de croissance en fonction de la lumière et de la température. *Annales de Limnologie.* 18 (3), 217-262.

De Loë, R.C. and R.D. Kreutzwiser, 2000. Climate variability, climate change, and water resources management in the Great Lakes. *Climatic Change.* 45(1), 163-179.

Droste, R.L., 1997. Theory and practice of water and wastewater treatment. J. Wiley & Sons, New York, NY.

Eamon, C., 2003. CANEAU Inc. Personal communication.

Eaton, S, 1996. An assessment of current practices and the need for change. *Environmental Science & Engineering.* 8(6), 107-110.

Evans, B., S., Nutt, T., Ho, and H Melcer, 1993. Alternative approaches for upgrading effluent quality for lagoon based systems. *Water Science & Technology.* 28(10), 201-205.

Espey, M., J. Espey and W.D. Shaw, 1997. Price elasticity of residential demand for water: A meta analysis. *Water Resources Research.* 33(6), 1369-1374.

Fisher, S., C. Liu, D. McKnight, O. Starosolszky, M. Taylor, D.G. Rutashobya and H.H.G. Savenije, 1996. Climate change 1995-Impact, adaptations and mitigations of climate change: scientific-technical analyses-Contribution of Working Group II to the second assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, NY.

Gélinas, J.P., 2004. Public works, Township of Alfred and Plantagenet. Personal communication.

GLIN (Great Lakes Information Network), 2003. Factors affecting Great Lakes-St. Lawrence system flows. www.great-lakes.net.

Government of Canada, 2002. Canadian environmental quality guidelines. www.ec.gc.ca.

Government of Ontario, 2003. *Water resources act.* Ontario statutes and regulations. www.e-laws.gov.on.ca.

Guertain, R., 2002. Superintendant, Ville de Hawkesbury. Personal comunication.

Harris, R. W., Cullinane M. J. and P. T. Sun, 1982. CapdetWorks-Technical reference Environmental Engineering Division, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksbburg, MI. Report # PB82-190455.

Hudon, C., 2000. Phytoplankton assemblages in the St. Lawrence River, downstream of its confluence with the Ottawa River, Quebec, Canada. *Canadian Journal of Fisheries and Aquatic Sciences.* 57(1), 16-30.

Hurd, B., N. Leary and J. Smith, 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association.* 35(6), 1399-1409.

IPCC (Intergovernmental Panel on Climate Change), 2001. Climate change 2001: working group 1: The scientific basis. *Climate Change 2001-IPCC Third Assessment Report.* www.grida.no

Industry Canada, 2004. *Problems of the environment-Evaluating, designing or optimizing waste water treatment.* www.strategis.ic.gc.ca

Jochimsen, E.M., W.W. Carmichael, J. An, D.M. Cardo, S.T. Cookson, C.E.M. Holmes, M.B. Antunes, D.A. de Melo Filho, T.M. Lyra, V.S.T. Barreto, S.M.F.O. Azevedo and W.R. Jarvis, 1998. Liver failure and death after exposure to microcystins at a hemodialysis center in Brazil. *New England Journal of Medicine.* 339(13), 873-878.

Karl, T.R. and R.W. Knight, 1998. Secular trends of precipitation amount, frequency, and intensity in the USA. *Bulletin of the American Meteorological Society.* 79(2), 231-241.

Kiehl and Trenberth, 1997. Earth's annual global mean energy budget. *Bulletin of the American Meteorological Society.* 78(2), 197-208.

Kiloran, S., 2002. Township of South Glengarry. Personal communication.

Lambert, T.W., Holmes C.F.B. and S.E.Hrudey, 1996. Adsorption of microcystin-LR by activated carbon and removal in full scale water treatment. *Water Resources.* 30(6), 1411-1422.

Lewis, J.E., 1989. Climatic change and its effects on water resources for Canada: A review. *Canadian Water Resources Journal.* 14(1), 34-35.

Lins, H.F. and E.Z. Stakhiv, 1998. Managing the nation's water in a changing climate. *Journal of the American Water Resources Association.* 34(6), 1255-1264.

Loudon, M. and M. Fortin, 1996. Full pricing of water and wastewater services. *Environmental Science and Engineering.* 9(5), 60-64.

Manoharan, M., 2004. Ontario Ministry of the Environment. Personal communication.

Mara, D.D., 1996. Waste stabilization ponds: effluent requirements and implications for process design. *Water Science and Technology*. 33(7), 23-31.

Masters G.M., 1998. Introduction to environmental engineering and science, second edition. Prentice Hall, Upper Saddle River, NJ.

Metcalf and Eddy, Inc., 1991. Water resources and environmental engineering, wastewater engineering, treatment, disposal and reuse, third edition. McGraw-Hill Inc, New York, NY.

Michelson A.M., McGuckin J.T. and D.M. Strumpf, 1998. Effectiveness of residential water conservation price and nonprice programs. AWWA Research Foundation and American Water Works Association, USA. 128 p.

Middlebrooks E.J., C.H. Middlebrooks, J.H. Reynolds, G.Z. Watters, S.C. Reed and D.B. Goerge, 1982. Wastewater stabilization lagoon design, performance and upgrading. Macmillan Publishing Co., Inc. NY.

Mimikou, M.A., E. Baltas, E. Varanou and K. Pantazis, 2000. Regional impacts of climate change on water resources quantity and quality indicators. *Journal of Hydrology*. 234, 95-109.

MOE (Ontario Ministry of the Environment), 1994. *Water management: policies, guidelines, provincial water quality objectives of the Ministry of the Environment.* www.ene.gov.on.ca

MOE (Ontario Ministry of the Environment), 2003a. *Drinking water surveillance program reports*. www.enegov.on.ca.

MOE (Ontario Ministry of the Environment), 2003b. www.ene.gov.on.ca.

MOE (Ontario Ministry of the Environment), 2003c. *Waste water discharge reports.* www.enegov.on.ca.

Murdoch, P.S., J.S. Baron and T.L. Miller, 2000. Potential effects of climate change on surface-water quality in North America. *Journal of the American Water Resources Association*. 36(2), 347-366.

Narbaitz, R. N., 2003. Civil Engineering Department, University of Ottawa. Personal communication.

Natural Resources Canada, 2002. *Climate change impacts and adaptation: A Canadian perspective*. Climate Change Impacts and Adaptation Dictorate, Ottawa. Report# M174-2/2004E.

Nichols, D.S., 1983. Capacity of natural wetlands to remove nutrients from wastewaters. *Journal of the Water Pollution Control Federation*. 55(5), 495-505.

NWRI (National Water Research Institute), 2001. *Threats to sources of drinking water and aquatic ecosystem health in Canada*. NWRI Scientific Assessment Report Series, Environment Canada, Burlington, Ontario.

OCWA (Ontario Clear Water Agency), 1998. Wastewater discharge database. Personal communication.

Odum, E. P., 1971. Fundamentals of ecology. Saunders, Philadelphia, Pensilvania.

Parkhurst, J., 1977. Pomona Virus Study, Sanitation Districts of Los Angeles County.

Pick, F., 2002. University of Ottawa. Personal communication.

Pielke R.A. and M.W. Downton, 2000. Precipitation and damaging floods: trends in the United States 1932-97. *Journal of Climate*. 13(20), 3625-3637.

Quasim S.R., 1994. Wastewater treatment plants: planning, design and operation. Technomic Publishing Company, Lancaster.

Quasim, S. R., Motley, E. M. and Z. Guang, 2000.Water works engineering: planning, design and operation. Prentice Hall PTR, Upper Saddle River, NJ.

Regional Municipality of Niagara, 1993. *Taste & odour control strategy*. Decew Falls water plant, Ontario.

Robinson, J.E. and E.E. Creese, 1993. Climate change and the municipal water systems of Cambridge, Kitchener and Waterloo. *The Impact of Climate Change on Water in the Grand River Basin, Ontario*. University of Waterloo, Department of Geography Publication Series no. 40, 159-188.

Rositano, J., Newcombe G., Nicholson, B. and P. Sztajnbok, 2001. Ozonation of NOM and algal toxins in four treated waters. *Water Resources*. 35(1), 23-32.

Rousselle, Y., 2004. Manager-Environment, Municipality of Clarence-Rockland. Personal communication.

RRCA (Raisin Region Conservation Authority), 2004. www.rrca.on.ca.

Southam, C.F., B.N. Mills, R.J. Moulton and D.W. Brown, 1999. The potential impact of climate change in Ontario's Grand River Basin: water supply and demand issues. *Canadian Water Resources Journal*. 24(4), 307-330.

Schmidt, W., Willmitzer, H., Bornmann, K. and J. Pietsch, 2002. Production of drinking water from raw water containing cyanobacteria-Pilot plant studies for assessing the risk of microcystin breakthrough. *Environmental Toxicology*. 17, 375-385.

Stahre, P. and B. Urbonas, 1990. Stormwater detention for drainage, water quality, and CSO management. Prentice –Hall, Inc., Englewood Cliffs, N.J.

Taylor, B.R. and A.N. Dykstra, 2002. Effects of hot ground water on a small swamp-stream in Nova Scotia, Canada. *Hydrobiologia*. 545, 129-144.

Tchobanoglous, G. and E.D. Schroeder, 1987. Water quality. Addison-Wesley Publishing Company, Reading, MA.

Thornthwaite, C., 1948. An approach towards a rational classification of climate. *Geographical Review*. 38, 55-94.

Tsagarakis, K.P., Mara, D.D. and A.N. Angelakis, 2003. Application of cost criteria for selection of municipal wastewater treatment systems. *Water, Air and Soil Pollution*. 142, 187-210.

Turseault, L., 2004. Ville de Ste-Agathe des Monts. Personal communication.

USEPA (United States Environmental Protection Agency), 2001. *Interim Enhanced Surface Water Treatment Rule: A Quick Reference Guide*. www.epa.gov/safewater.

Vogel, J., E. Royal and V. Snoeyink, 1997. Zebra mussels linked to taste, odour problems. *Opflow, AWWA*. 23(7), 4-5.

Waite, T.D., 1984. Principles of water quality. Academic Press, Orlando, FL.

Watson, S., B. Brownlee, T. Satchwill and E. McCauley, 1999. The use of solid phase microextraction (SPME) to monitor for major organoleptic compounds produced by chrysophytes in surface waters. *Water Science and Technology*. 40, 251-256.

WHO (World Health Organization), 1996. Guidelines for drinking water quality. Vol.2.

Wilkinson, H., 2002. Ontario Clean Water Agency. Personal communication.

Willcocks, R, 2000. Evolution of lagoon effluent enhancement to meet stringent effluent criteria. *Environmental Science & Engineering*. 13(3), 60-62.

Wright D.G., Patry G.G., Letman C.E. and D.R. Woods, 1988. A procedure for estimating the capital cost of Ontario wastewater treatment plant using CAPDET. *Canadian Journal of Civil Engineering*. 15, 799-806.

Young R.A., C.A. Onstad, D.D. Bosh and W.P. Anderson, 1989. AGNPS: a non-point source pollution model for evaluating agricultural watersheds. *Journal of Soil and Water Conservation*. 44, 168-173

APPENDIX A : Water and Sewage Infrastructure Management

Water and Sewage Infrastructure Management in the United Counties of Stormont, Dundas, Glengarry and Prescott and Russell

Municipality	Number of Water Treatment Facilities	Number of sewage treatment Facilities	Authority over Water Treatment Facilities' Operations	Authority over Sewage Treatment Facilities' Operations	Authority over Distribution and/or Collection Systems
United Counties of Stormont, Dundas and Glengarry					
North Glengarry	2	2	Municipal	Municipal	Municipal
South Glengarry	3	3	Municipal	Municipal	Municipal
North Dundas	10	2	OCWA	OCWA	OCWA
South Dundas	2	3	CANEAU	CANEAU	Municipal
North Stormont	7	2	OCWA	OCWA	OCWA
South Stormont	2	2	CANEAU	CANEAU	Municipal
United Counties of Prescott and Russell					
Alfred-Plantagenet	3	3	OCWA	OCWA	Municipal
Casselman	1	1	Municipal	Municipal	Municipal
Champlain	1	1	OCWA	OCWA	OCWA
Clarence-Rockland	6	1	OCWA	OCWA	Municipal
East Hawkesbury	0	3	OCWA	OCWA/Municipal	OCWA/Municipal
Hawkesbury	1	1	Municipal	OCWA	Municipal
Nation	3	3	OCWA	OCWA	OCWA
Russell-Embrun	2	2	Municipal	Municipal	Municipal

APPENDIX B : Survey Questionnaires

<u>WATER TREATMENT PLANT SURVEY</u>

The WTP survey questionnaire presented to the operating and managing personnel had 19 questions, each pertaining to different capacity and quality concerns. The 19 questions are presented below, followed by a brief description of the objective persued in raising each question.

<u>Question 1</u>: Have you experienced water quantity problems during the past 10 years? If so, can they be associated with weather or any other event?

<u>Objective:</u> Investigate the plant's vulnerability to water scarcity problems under current climate variations.

<u>Survey Results Summary:</u> Three facilities reported they had experienced water quantity problems. At Alexandria WTP, it was mentioned that the water source (Mill Pond) was limited so that during high demand or dry weather there has been water shortages. Both Alexandria and Hawkesbury staff mentioned 1990 as being a year where shortages of water occurred because of high demand as a result of a hot summer. At Rockland, it was mentioned they had experienced water quantity problems in 1999 because of dry weather season and high demand.

<u>Question 2</u>: Have there been water shortages during high demand periods?

<u>Objective:</u> Verify if the facility can provide for current peak demands.

<u>Survey Results Summary:</u> Alexandria, Alfred-Lefaibvre and Rockland have experienced water shortages during high demand periods. Glen Walter and Hawkesbury (not since 1996 (year the plant was expanded) have reportedly not experienced water shortages during high demand periods.

<u>Question 3</u>: Have you observed an increase in water demand during drought periods? If so, by how much?

<u>Objective:</u> Learn about costumer's behaviors during a drought period and how it may affect water demand. If the water demand increased significantly during a drought period, it should be considered that this trend will be exacerbated by climate change impacts and extrapolations may be possible based on projected longer dry periods.

<u>Survey Results Summary:</u> Most facilities experience an increase in water demand during summer months. The increase varies from more than 100% (Glen Walter) to very little (Wendover). Only Alexandria mentioned that there was no increase in demand during dry and hot periods because their distribution system is 100% metered.

<u>Question 4</u>: Number of water-use restriction days in a dry year? In an average year? In a wet year?

<u>Objective:</u> Have an indication of how the system is vulnerable to water shortages, and possibly correlate the possible number of water-use restriction days with the amount and pattern of precipitation for a given year.

<u>Survey Results Summary:</u> Only Glen Walter and Rockland reported using water restriction days (no numbers were available). No information on water-use restrictions was obtained for the other facilities.

<u>Question 5</u>: Any observations or specific problems during drought periods?

<u>Objective:</u> Establish if characteristics of the water change during dry periods. Also, identify if some treatment difficulties were encountered during drought periods.

<u>Survey Results Summary:</u> It was reported that water was very hard to treat during dry periods at Plantagenet (South Nation River) and that increased control and chemicals

(about 25%) was necessary in order to maintain the water quality. At other facilities, no other observations than the increases in water demand mentioned in questions 2 and 3 were reported.

Question 6: Have there been any concerns about taste and odors recently (past 5 years)? If so, can these problems be associated with any special weather event or any other event?

Objective: Gather information about taste and odor problems in order to possibly associate them with particular weather events, or particular years. If such associations can be made, projections for more intense conditions that favor taste and odor problems can be made.

Survey Results Summary: Alexandria, Glen Walter, Long Sault, and Hawkesbury reported taste and odor problems. For the Hawkesbury plant, the problem generally occurs during spring.

Question 7: Are there any seasonal algae bloom problems? If so, what are the consequences from a water quality perspective?

Objective: Establish if seasonal algal blooms are a source of problems. It is suspected that algal blooms could be enhanced by climate change. Utilities that currently have problems caused by algal blooms (such as taste, odor, and color) could see these problems exacerbated in the future.

Survey Results Summary: Alexandria and Hawkesbury (during August and September) reported that algal blooms were a source of problems.

<u>Question 8</u>: **Have you noticed other water quality problems during the past 5 years? If so, can they be associated with different types of weather or any other event?**

<u>Objective:</u> Identify any other type of problems not mentioned in the previous questions.

<u>Survey Results Summary:</u> At Hawkesbury, heavy rains and winds have for effect to increase raw water turbidity. Turbidity problems have also been reported for Plantagenet and Long Sault.

<u>Question 9</u>: **How many boil-water days have you had in a stormy year? In a dry year? In a wet year?**

<u>Objective:</u> Have an indication of the system's vulnerability to quality deterioration caused by storms, and possibly correlate the number of boil-water days with the amount and pattern of precipitation for a given year. In a future with more intense storms, sources of water currently vulnerable to quality deterioration caused by storms may require more frequent boil-water days if the plant and/or personnel cannot adapt to these events.

<u>Survey Results Summary:</u> No facilities reported having any boil-water days in the recent years (1999 to 2003).

<u>Question 10</u>: **Any observation on water quality during maximum flow events?**

<u>Objective:</u> Verify the extent of maximum flow events impacts on raw water quality, this should allow for extrapolations for more intense weather events in the future.

<u>Survey Results Summary:</u> Plantagenet and Long Sault reported increased turbidity during maximum flow events.

<u>Question 11</u>: **Any observation on water quality during wet years or wet periods?**

<u>Objective:</u> Identify any other type of problems, related to wet weather, which were not mentioned in the previous questions.

Survey Results Summary: No other type of problem was reported in regards to wet years or wet periods.

Question 12: Any other special observations or concerns (ex: change in water characteristics over the years)?

Objective: Identify any other type of problems in general which were not mentioned in the previous questions.

Survey Results Summary: No other type of problem was reported.

Question 13: Are there any water restrictions (by-law)?

Objective: Investigate the facility's current needs and practices.

Survey Results Summary: Alexandria, Alfred-Lefaivre, Casselman, Glen Walter, Hawkesbury, Ingleside and Long Sault reported using water restrictions.

Question 14: What is the life expectancy of the plant? Is an expansion planned for the near future?

Objective: Identify if current possible problems will be solved with planned works on the facility, or the replacement of that facility.

Survey Results Summary: Life expectancy for the Alfred-Lefaivre, Iroquois and Plantagenet facilities is approximately 20 years. Casselman was completely upgraded recently. The Alexandria facility required expansion 5 years ago. Instead, metering was implemented and the facility now has sufficient capacity. The Ingleside and Rockland facilities will require major repairs or replacement within 5 years. A new facility is expected to replace the Long Sault and Morrisburg facilities.

Question 15: Do you have a storage reservoir? If so, what is its capacity?

Objective: Establish the extra capacity per consumer that is available and the capacity of the facility to deal with supply and demand variations.

Survey Results Summary: The storage capacity of the study area's facilities are as follows: Alexandria: 4546 m^3, Alfred-Lefaivre: 1562 m^3, Casselman: 2000 m^3, Glen Walter: 585 m^3, Hawkesbury: 10 000 m^3, Ingleside: 581 m^3, Iroquois: 950 m^3, Long Sault: 581 m^3. Morrisburg: 950 m^3, Plantagenet: 782 m^3, Rockland: 4 545 m^3 and Vankleek Hill: 2 270 m^3.

Question 16: Is the reserve capacity of the source water known?

Objective: Identify potentially vulnerable water source to water scarcity.

Survey Results Summary: No specific information on the potential reserve capacity of the sources of water was obtained.

Question 17: Is there water metering within the community? If so, what percentage of the distribution system is metered? Or what percentage of the demand is metered?

Objective: Investigate the facility's current practices and its vulnerability to high increase in water demand during dry periods.

Survey Results Summary: Most communities of the study area have water metering. Alexandria has 100% of its system metered. Casselman, Iroquois, Morrisburg, Plantagenet, Rockland and Vankleek Hill all have metering but details on the percentage or the structure of the metering were not obtained. Hawkesbury has all industries and 50% of its businesses metered. Residences in Hawkesbury are not metered. Long Sault also has industries metered but not the residences. At the time of the survey, Glen Walter did not have metering on its system but was planning to implement it the same year.

Question 18: What is the elevation of the intake and how deep is it located in the driest cases?

Objective: Determine if future more intense drought periods will require the installation of a deeper raw water intake.

Survey Results Summary: At Alexandria the level of the pond is controlled (so the depth of the intake is constant). At Hawkesbury the intake is 15-20 feet deep. At Long Sault the intake is 30 feet deep.

WASTEWATER TREATMENT PLANT SURVEY

The WWTP survey questionnaire had 12 questions, each pertaining to different capacity and quality concerns. This section presents the questions asked to the facilities personnel, as well as a brief description of the concerns associated with each of the 12 questions.

Question 1: What percentage of the collection system is combined sewer?

Objective: Investigate the facility's likeliness of having to by-pass partially treated wastewater. In combined sewer systems, storm water is collected along with wastewater to be taken to the treatment facility. The storm water will dramatically increase the wastewater treatment facility's influent flowrates, sometimes causing the influent flowrate to exceed plant capacity. The exceeding part of the influent diluted wastewater has to be temporarily bypassed after receiving only partial or no treatment prior to discharge.

Survey Results Summary: Hawkesbury has small parts of its collection system which is combined. Glen Walter, Ingleside, Long Sault and Vankleek Hill all have separated collection systems. The type of collection systems for the other facilities of the study area was not specified during the survey.

Question 2: Do you know of any infiltration problems in the sewers system?

Objective: To investigate the influence that rain events have on the facility's influent flows as well as the facility's likeliness of having to by-pass partially treated wastewater. Rainwater can enter the collection system through infiltration and increase the wastewater treatment facility inflow during rain events to a point where the total inflow cannot be treated and part of it has to be bypassed.

Survey Results Summary: Glen Walter, Hawkesbury, Ingleside, Iroquois, Long Sault, L'Orignal and Rockland all reported having infiltration problems on their collection system. Glen Walter and L'Orignal have performed some rehabilitation work and removal of illegal connections on their collection systems in order to minimize the infiltration problem. Only Vankleek Hill reported having a low level of infiltration on its collection system.

Question 3: Any observations on maximum flow events?

Objective: Establish if the characteristics of the wastewater change during such events. In addition, verify if some treatment difficulties can be associated with maximum flow events.

Survey Results Summary: Hawkesbury and L'Orignal have to bypass partly treated wastewater during maximum flow events. Glen Walter reported that during maximum flow events there was a dilution of raw wastewater, however, no effect on effluent quality was observed.

<u>Question 4</u>: Any observations or specific problems during drought periods?

<u>Objective:</u> Investigate if the characteristics of the wastewater changed during such events.

<u>Survey Results Summary:</u> No observations or specific problems during drought periods were reported during the survey.

<u>Question 5</u>: Any observations on variations in seasonal process performance?

<u>Objective:</u> Investigate if characteristics of the wastewater change with seasonal changes. Additionally, investigate if treatment difficulties can be associated with seasonal changes. A seasonal change in wastewater characteristic and treatment approaches could have implications in a changing climate context as the seasonal pattern is expected to be affected by climate change.

<u>Survey Results Summary:</u> No observations on variations in seasonal process performance were reported during the survey.

<u>Question 6</u>: Are there any other special observations or concerns?

<u>Objective:</u> Raise any observations that were not mentioned in the previous questions.

<u>Survey Results Summary:</u> No other observations or concerns were reported during the survey.

<u>Question 7</u>: What are the effluent requirements on the certificate of approval?

<u>Objective:</u> Investigate if the facility has any special requirements that would reflect the vulnerability of its receiving waters. Verify if requirements are met, and investigate if such requirements would be adequate in the case of a decreased dilution capacity of the receiving waters (during a more severe drought for example).

Survey Results Summary: With the exception of Vankleek Hill, all of the study area wastewater treatment plants have to comply with the MOE requirements for secondary treatment systems (25 mg/L BOD, 25 mg/L SS and 1 mg/L TP). Vankleek Hill is a rotating biological reactor added upstream of an existing lagoon system, the effluent requirements for this facility are 15 mg/L BOD, 20 mg/L SS and 1 mg/L TP.

Question 8: Where (in what stream) exactly the plant discharges its treated water?

Objective: Investigate the extent to which the receiving waters are vulnerable to drought. As well as verify the receiving waters vulnerability to changing effluents quality.

Survey Results Summary: The Glen Walter, Ingleside, Iroquois and Long Sault facilities effluents are discharged to the St. Lawrence River. The L'Orignal, Hawkesbury, Chute à Blondeau, Rockland and Wendover facilities effluents are discharged to the Ottawa River. The Vankleek Hill facility's effluent is discharged to the Little Rideau Creek.

Question 9: How frequently is bypass needed?

Objective: Investigate the extent of the bypass problem under current conditions. With more extreme rain events, the actual extent of bypass would be exacerbated.

Survey Results Summary: No information on the frequency of bypass was obtained during the survey.

Question 10: Is there any equalization capacity at the moment?

Objective: Determine the capacity of the plant to deal with inflows variability caused by more intense rain events.

Survey Results Summary: It was reported that the pumping station at the Ingleside facility offered a certain equalization capacity. No other facility had equalization capacity at the time of the survey. However, at the Hawkesbury plant, there was a plan for construction of an equalization basin in the coming years.

Question 11: Is an expansion planned for the near future?

Objective: Investigate the capacity of the plant to deal with higher inflows caused by more intense rain events.

Survey Results Summary: Life expectancy for the Ingleside, Rockland, Wendover and Long Sault facilities is approximately 20 years. The Hawkesbury facility will require major repairs or replacement within 5 years.

LAGOON SYSTEMS SURVEY

The lagoon systems survey questionnaire had 14 questions, each pertaining to different capacity and quality concerns. This section presents the questions asked to the facilities personnel, as well as a brief description of the concerns associated with each of the 14 questions.

Question 1: What percentage of the collection system is combined sewer?

Objective: Investigate the likeliness that the hydraulic retention time is shortened, causing incomplete treatment of the wastewater prior to discharge. In combined sewer systems, rainwater is collected along with wastewater to be taken to the treatment facility. During extended wet periods, the volume of water taken to the lagoon systems through combined sewers might exceed the actual lagoon capacity. However, it should be noted that in the case of annual or semi-annual discharge lagoon systems, the retention times are very long. For this type of system, an early discharge for capacity reasons should not affect the effluent quality.

Survey Results Summary: Alexandria, Chesterville, Crysler, Embrun, Green Valley, Maxville and Winchester all have separated collection systems. The type of collection system for the other facilities of the study area was not specified during the survey.

Question 2: Do you know of any infiltration problems in the sewers system?

Objective: Investigate the collection system's situation for the facility. Infiltration problems might not have any observable effects on lagoon system treatment, but in the event of a replacement of the lagoon system by a mechanized plant, it will be important to know the degree of infiltration on the collection system.

Survey Results Summary: Alexandria, Chesterville, Green Valley, Lancaster, Morrisburg St-Albert, Plantagenet, Russel and Winchester all reported having infiltration problems on their collection system.

Question 3: Where (in what stream) exactly the plant discharges its treated water?

Objective: Investigate the extent to which the receiving waters are vulnerable to drought. Also, to verify the receiving waters vulnerability to changing effluents quality.

Survey Results Summary: The Casselman, Chesterville, Crysler, Plantagenet and St-Albert lagoons effluent are discharged to the South Nation River. The Alexandria lagoon's effluent is discharged to the Delisle River. The Alfred lagoon's effluent is discharged to the Azatika Brook Creek. The Embrun and Russel lagoons effluent are discharged to the Castor River. The Green Valley lagoon's effluent is discharged to the Beaudelais River. The Lancaster lagoon's effluent is discharged to the Finney Creek. The Maxville and St-Isidore lagoon's effluent are discharges to the Scotch River. The Moose Creek lagoon's effluent is discharged to the Moose Creek. The Morrisburg lagoon's effluent is discharged to the St. Lawrence River. The Williamsburg lagoon's effluent is discharged to the Mc Martin Drain and the Winchester lagoon's effluent is discharged to the Henderson Creek.

<u>Question 4</u>: Are there any observations on wet years or wet periods?

<u>Objective:</u> Verify if the lagoon systems have sufficient volume to be able to hold all of the rainwater from a wet year (for annual and semi-annual discharge systems). To identify any other type of problems related to wet weather.

<u>Survey Results Summary</u>: At Alexandria, the enhanced dilution during wet periods has for effect to improve effluent quality. At Lancaster, dilution of the lagoon's content was also observed. At Plantagenet, more overflow (effluent discharged outside of the discharge period) was observed during wet periods.

<u>Question 5</u>: Any observation on maximum flow events?

<u>Objective:</u> Establish if characteristics of the wastewater change during such events.

<u>Survey Results Summary:</u> No observations during maximum flow events were reported during the survey.

<u>Question 6</u>: Are there any observations or specific problems during drought periods?

<u>Objective:</u> Establish if characteristics of the wastewater change during such events.

<u>Survey Results Summary:</u> At the Winchester lagoon, it was reported that high ammonia levels in 2002 may have been the result of dry weather. At Lancaster, the discharge stops during dry periods.

Question 7: Are there any seasonal algal bloom problems? If so, what are the consequences from a water quality perspective?

Objective: If there are seasonal algae problems, and if the effluent quality is affected by such problems, it can be expected that the effluent quality would be further affected by climate change enhanced algal growth.

Survey Results Summary: Seasonal algal blooms were observed at the Plantagenet, Chesterville, Maxville and Winchester lagoons. At Maxville, Winchester and Plantagenet algal blooms were associated with increased effluent SS concentrations.

Question 8: Does the lagoon system have a surface runoff diversion system?

Objective: To investigate the facility is able to divert surface runoff around the pond in times of heavy rain.

Survey Results Summary: Only the Green Valley lagoon reported having a surface runoff diversion system.

Question 9: Is there any erosion of the lagoons interior slope that you know of? If so, do you have treatment or maintenance problems as a consequence of this erosion?

Objective: Establish if there are currently erosion problems. It is believed that intensified climatic conditions (heavier winds and rain), like those predicted by climate change, could accelerate the rate of erosion.

Survey Results Summary: At the Winchester lagoon, minimum erosion problems have occurred.

Question 10: Are there any solids accumulation problems? Are the solids pumped out? Objective: Investigate if there are any problems with solids accumulation at the bottom of the lagoons. Solids accumulation at the bottom of the lagoons could be accelerated by increased erosion and solids transport during heavy rain events, as well as increased growth of algae. Solids accumulation decreases the actual volume where the treatment occurs, involving a decrease in the retention time, and possibly a decrease in treatment efficiency.

Survey Results Summary: Some solids were pumped out the Plantagenet lagoon in 2002. At Winchester one cell was undergoing sludge removal during the survey. Sludge removal at Winchester is done by drying the cell and then solids are removed by a bulldozer. No further solids accumulation problems were reported for the study area during the survey.

Question 11: Are there any other special observations or concerns?

Objective: Raise any observations that were not mentioned in the previous questions.

Survey Results Summary: No other specific observations or concerns were reported during the survey.

Question 12: What are the effluent requirements on the certificate of approval?

Objective: Investigate if the facility has any special requirements that would reflect the vulnerability of its receiving waters. Verify if requirements are met and investigate if such requirements would be adequate in the case of a decreased dilution capacity of the receiving waters (during a more severe drought for example).

Survey Results Summary: The study area lagoon systems have to comply with the following requirements:

Alexandria and Winchester: 30 mg/L BOD, 40 mg/L SS and 1 mg/L TP

Alfred: 30 mg/L BOD, 40 mg/L SS

Casselman, Chesterville, Maxville, Plantagenet and St-Isidore: 25 mg/L BOD, 25 mg/L SS and 1 mg/L TP.

Lancaster: 25 mg/L BOD, 25 mg/L SS

Embrun 30 mg/L BOD, 30 mg/L SS and 1 mg/L TP, 20 mg/L ammonia in spring and 4 mg/L ammonia in fall

Green Valley: 30 mg/L BOD, 30 mg/L SS and 1 mg/L TP

Morrisburg: 30% removal for BOD and 50% removal for SS

Russel: 30 mg/L BOD, 40 mg/L SS and 1 mg/L TP, 20 mg/L ammonia in spring and 4 mg/L ammonia in fall

St-Albert: 30 mg/L BOD, 30 mg/L SS and 1 mg/L TP, 220 mg/L NH_3+NH_4, 0.32 mg/L H_2S in March and 0.89 mg/L H_2S L in April

Williamsburg 30 mg/L BOD, 40 mg/L SS

<u>Question 13</u>: Is an expansion planned for the near future?

<u>Objective:</u> Investigate the capacity of the lagoon system to provide for increased volume of wastewater. Some lagoon systems are currently operating at or over capacity, this situation does not offer much buffering capacity for possible increase in wastewater volume.

<u>Survey Results Summary:</u> Life expectancy for the Alexandria, Crysler, Maxville, Plantagenet, St-Albert, St-Isidore and Williamsburg facilities is approximately 20 years. The Embrun, the Moose Creek and the Russel facilities will require major repair or replacement within 10 to 20 years. The Alfred, Casselman, Chesterville and Morrisburg facilities will require major repairs or replacement within 5 years.