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Overview of Protozoa in the North Saskatchewan River Basin

By

Cindy Dawn Shepel 

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

In

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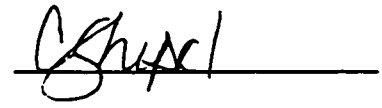

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Overview of Protozoa in the North Saskatchewan River Basin submitted by Cindy Dawn Shepel in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering.

Dr. S. J. Stanley

Dr. D. W. Smith

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Date: 15 April 2000

ABSTRACT

This study quantified all types of sources of *Cryptosporidium* spp. and *Giardia* spp. in a watershed. The study was designed to assess the water quality throughout the basin, and to determine the contaminant contribution to the basin.

The study found that the largest contribution to both *Cryptosporidium* spp. and *Giardia* spp. loadings came from the small percentage of creeks that were sampled within the basin. Wastewater treatment plants contributed a substantial load of *Giardia* spp. during the winter months, and they provided a baseline contribution of the protozoa over the year. The sewage treatment lagoons that discharged during the spring had substantially higher *Cryptosporidium* spp. loadings than those that discharged during the summer and late fall. The *Giardia* spp. concentrations in the sewage effluent were not as high as the *Cryptosporidium* spp. concentrations. Further investigation into how farm management practices affect the contribution of both protozoa are warranted.

Dedicated to my loving husband,

Tyler Daniel Shepel

It was his unending love and gentle encouragement that truly made this thesis what it is. His support emotionally and mentally was endless, greatly needed and very appreciated.

You are my shining star!

As well, I would like to thank my parents,

Ken and Gail Robinson

It was because of their tremendous encouragement and belief in me that I pursued this Master of Science degree. The life lessons they have taught me are infinite, the most of which are: the confidence to attempt; and, the determination to succeed.

You have always believed!

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List of Symbols and Abbreviations

d	day
EPCOR	Edmonton Power Corporation
g	acceleration of gravity
h	hour
Hg	mercury
km	kilometre
km^2	square kilometre
KPa	kilo Pascal
min.	minute
ML/d	million litre per day
mL	millilitre
NSR	North Saskatchewan River
STL	sewage treatment lagoon
µL	microlitre
µm	micrometre
UV	ultra violet
WTP	water treatment plant
WWTP	wastewater treatment plant

1.0 INTRODUCTION

In recent years, several municipalities in North America have had outbreaks of cryptosporidiosis and giardiasis. This has led to an increasing interest in determining sources of these protozoan parasites, particularly with respect to drinking water supplies. Although transmission of *Cryptosporidium* spp. and *Giardia* spp. has been linked to the water source for some outbreaks in Canada, the role of treated tap water in transmission of these parasites remains unclear. Testing for *Cryptosporidium* spp. and/or *Giardia* spp. in treated water is costly, particularly for small water treatment facilities. Very few water treatment plants in Alberta monitor raw or treated water for these parasites, even though Alberta Environment encourages them to do so.

The control of *Cryptosporidium* spp. and *Giardia* spp. challenges both water and public-health officials as there are limited methods available to sufficiently eliminate or inactivate the organisms from drinking water. The use of some microorganism reduction chemicals to treat drinking water supplies has been incapable of fully inactivating the organism (Smith and Rose 1990; Addiss et al. 1995). Currently, chemical oxidation using ozone, physical removal of the oocysts and cysts ((oo)cysts) by membrane units and photo inactivation by U. V. light are the best techniques to remove *Cryptosporidium* spp. and *Giardia* spp. from drinking water. However, conventional water filtration does not completely

remove the organism (Smith and Rose 1990; LeChevallier et al. 1991; Addiss et al. 1995; Goldstein et al. 1996).

EPCOR Water Services Inc. (EPCOR), is the third largest water distributor in Canada. In the City of Edmonton, EPCOR owns and operates two water treatment plants (WTPs, the EL Smith WTP and the Rossdale WTP, 520 million liters per day [ML/d] total capacity), providing drinking water to 815 000 people in the City and surrounding regions (636 000 in Edmonton, and 179 000 in 40 communities within 100 kilometre (km) radius of the city). The water supply for EPCOR's two WTPs in the City of Edmonton is the North Saskatchewan River (NSR), which originates in the Rocky Mountains (Figure 1.1). Source protection is the first step in the multiple-barrier approach to drinking water treatment that EPCOR has adopted. Ensuring that the source of drinking water is as clean as possible helps safeguard the health of the water utility's customers, and ensures the environmental integrity of the NSR without compromising the economic well being of its users. In order to develop an understanding of how activities within the watershed impact the water quality, EPCOR has adopted an intensive sampling program at the treatment plant, and has one of the most extensive historical databases of source water concentrations of *Cryptosporidium* spp. and *Giardia* spp. in North America.

A successful watershed program requires the cooperation and commitment of all stakeholders, including municipalities, provincial and federal governments,

landowners and water utilities. This study was performed only as a result of the strong working partnership of Alberta Agriculture, Food and Rural Development, Alberta Environment, EPCOR, Prairie Farm Rehabilitation Administration, Alberta Research Council, Alberta Health, Health Canada, and researchers from the University of Calgary and the University of Alberta. Water samples were collected by Alberta Environment, and sample collection costs were provided as in-kind support from Alberta Environment. Turbidity and protozoan water samples were processed by EPCOR, and these sample processing costs were provided as in-kind support from EPCOR. The bacteriological and chemical water samples were processed by the Provincial Laboratory in Edmonton, Alberta Research Council in Vegreville and Environ-Test in Edmonton. Bacteriological and chemical sample processing costs were provided by funding from Alberta Health, and Health Canada.

Knowledge from this large-scale watershed program may be used to reduce the risk from increased concentrations of *Cryptosporidium* spp. and *Giardia* spp. in source water, especially during spring runoff when levels are notably high each year.

Specifically, this study has focused on a thorough investigation of the NSR upstream of, and including, the City of Edmonton. The study was designed to assess the water quality throughout the basin, as well as to determine the contaminant contribution to the NSR during spring runoff, summer rainstorm and

low flow events. The intensive investigation of a watershed of this size is the first of its kind in North America, and will provide data as well as a model of a sampling program that will be useful to other areas in North America.

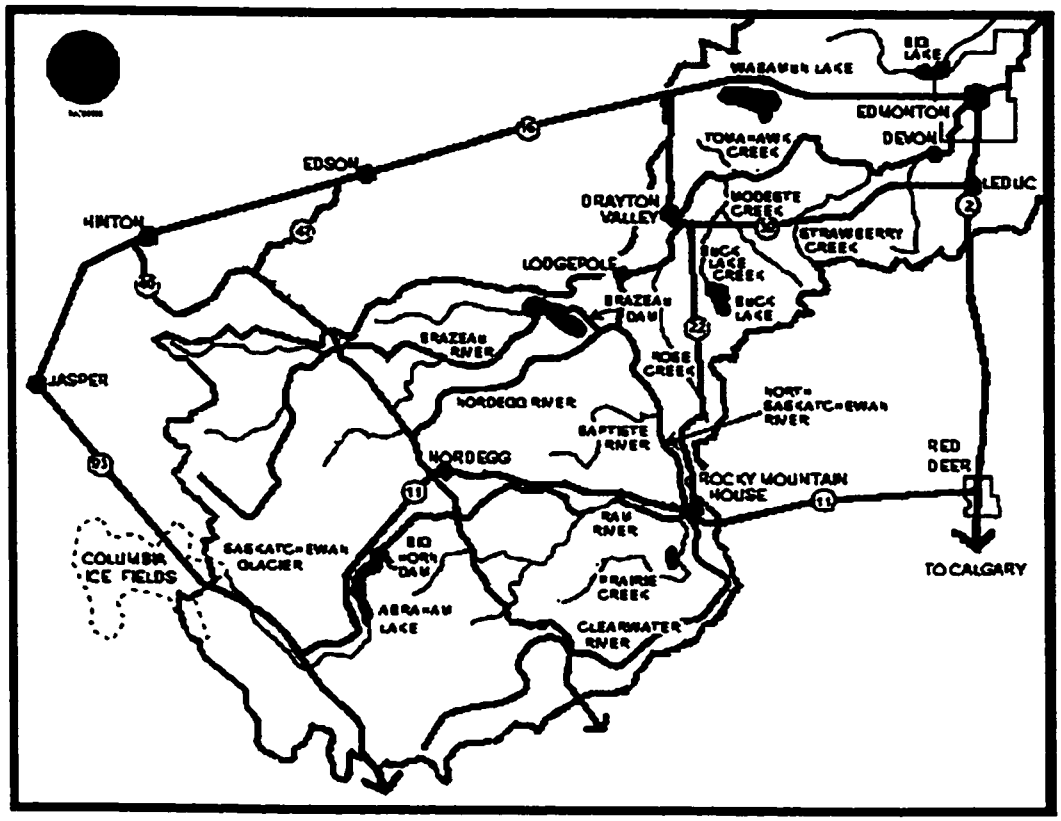

Figure 1.1: North Saskatchewan River Basin Upstream of, and Including, the City of Edmonton (EPCOR; March 3, 2000)

1.1 Background

Cryptosporidium spp. and *Giardia* spp. are intestinal protozoa, which can cause a severe diarrhea that may be life threatening in the immunocompromised (Ungar 1994). These protozoa in drinking water have caused more reported waterborne disease outbreaks in Canada, the United States, and other countries than any other single known pathogen (USEPA, 1995). Wallis et al. (1996) suggest that

the incidence of waterborne cryptosporidiosis and giardiasis is probably greatly underestimated in Canada. Craun (1990) reported that starting in the 1970's there was an increasing awareness of waterborne outbreaks due to *Giardia lamblia*, especially in communities using unfiltered surface water sources. Waterborne outbreaks due to *Cryptosporidium parvum* began to be detected in the mid 1980's, and in Milwaukee in 1993, it was responsible for the largest outbreak in US history (MacKenzie 1994). *Cryptosporidium* spp. and *Giardia* spp. are more resistant to environmental stresses and chemical treatment than almost all other known waterborne pathogens. The environment may become contaminated through direct deposits of human and animal feces or through sewage and wastewater discharges to receiving waters (American Public Health Association, 1998).

Surveys conducted to date have demonstrated the wide distribution and occurrence of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in raw and treated water supplies (LeChevallier 1991; Rose 1991; LeChevallier 1991). The waterborne parasites, *Cryptosporidium* spp. and *Giardia* spp., have been found in a large percentage of surface waters studied in North America (Ongerth 1987; Rose 1990; LeChevallier 1991; Ong 1996). Many waterborne outbreaks of the intestinal illnesses cryptosporidiosis and giardiasis have been reported in the United States and Canada (Moore 1993; Craun 1990; Rose 1997). Water appears to be an important vector for the transmission of these parasites, along with direct contact with infected individuals. *Cryptosporidium* spp. and *Giardia*

spp. occur in wild and domestic animals, as well as in humans. Both parasites produce robust (oo)cysts that are able to endure environmental stress. The (oo)cysts are shed by infected persons or animals and enter surface water through direct fecal input, discharge of treated and untreated sewage, and runoff from agricultural lands (Medema 1998).

The river basin upstream of Edmonton is very large with the majority of the upper portion of the basin remaining undeveloped. The land in the lower portion of the basin is used primarily for agricultural production. Varied use makes it difficult to categorize and understand the effects of potential sources of protozoa (Crockett 1997). Watershed monitoring studies suggested that a watershed with various potential sources of *Cryptosporidium* spp. and *Giardia* spp., such as the NSR basin, would have significantly high occurrences and peak concentrations of *Cryptosporidium* spp. and *Giardia* spp. (Ongerth 1989; Hansen 1991; LeChevallier 1991; Rose 1991). It is suspected that during spring runoff and summer storms, the creeks in the lower basin could flush accumulated livestock waste into the NSR, contributing to the increased presence of the protozoa *Cryptosporidium* spp. and *Giardia* spp. in the river at these times.

Contaminated sewage effluents are also recognized as potential sources of waterborne parasites (Bukari et al. 1997). However, no information exists in Alberta on the prevalence of *Cryptosporidium* spp. or *Giardia* spp. in municipal

sewage facilities in rural communities or the ability of small facilities to remove these two parasites from the treated wastewater.

A previous study (Isaac-Renton 1996) has shown that drinking water samples collected from unprotected watersheds are frequently contaminated with *Cryptosporidium* spp. and *Giardia* spp. As well, little data is available from water treatment plants in small rural communities to indicate whether they are at a similar or higher risk to waterborne parasites than larger cities.

It is difficult to interpret monitoring data to explain the occurrence of protozoa and to identify sources. With the present sampling and analysis methods, it is impossible to collect enough samples over one or two years to explain occurrences of protozoa under the variety of seasonal and flow conditions that occur in a large watershed. Other information, such as watershed characteristics, must also be integrated into a research study to help explain the monitoring data. Identifying land uses associated with sources of protozoa and establishing the relative predominance of their effects based on flow conditions (significance of runoff during wet weather) enables identification of the type of pollution (point or nonpoint), its general location (immediate or upper regions of watershed), and its frequency (daily or wet weather only).

1.2 Problem Statement

This study investigates the presence of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in a large watershed located in the Province of Alberta in western Canada.

Recent studies in Alberta have shown that agriculture can affect surface water quality by elevating levels of nutrients and bacteria. However, there is limited information available to determine if agriculture in cold climates is a significant source of waterborne pathogens in surface waters. High levels of *Cryptosporidium* spp. and *Giardia* spp. in the raw drinking water supply at Edmonton, Alberta in 1997 led to the development of a three-year research project, which was initiated in March 1998, and included water quality monitoring and a parasite prevalence survey to identify potential watershed sources of *Cryptosporidium* spp. and *Giardia* spp. in the NSR basin. The collaborative effort of this project included: Alberta Agriculture, Food and Rural Development; EPCOR Water Services Incorporated; Alberta Environment, Water Sciences Branch and Monitoring Branch; Alberta Health; Health Canada; Alberta Research Council; Prairie Farm Rehabilitation Administration, University of Calgary; and, the University of Alberta. This thesis contains the water quality monitoring results for the first two years of this three-year study. Sources targeted for investigation included municipal sewage effluent, agriculture and wildlife.

One component of this project included monitoring wastewater treatment facilities and drinking water treatment plants in small and medium sized municipalities to assess the presence of *Cryptosporidium* spp. and *Giardia* spp. in their raw and treated effluent products. These data were used to determine the contributions to the river and provide an indication of the level of risk of waterborne parasites to the people in the basin. There are 6 conventional WTPs in the NSR basin upstream of, and including, the City of Edmonton. The NSR supplies source water for all of these WTP. There are 4 continuously discharging wastewater treatment plants (WWTP) in the NSR basin upstream of and including the City of Edmonton. In addition, there are 13 sewage treatment lagoons (STL) that periodically discharge their effluent into rivers or creeks that flow directly into the NSR upstream of the City of Edmonton. For these STLs, their contribution to the presence of *Cryptosporidium* spp. and *Giardia* spp. in the NSR basin could only occur during their discharge period, which is for a maximum of three weeks for each lagoon. The lagoons may discharge at any time from March to the end of November. Therefore, lagoons discharging during the spring runoff period may be greater contributors to the loadings observed at EL Smith WTP than lagoons that discharge during late summer or fall.

Another component of this study involved an extensive longitudinal study of twenty major tributaries flowing into the NSR. Each tributary was sampled near its mouth, prior to its confluence with the NSR. Samples were taken during three distinct flow periods: spring runoff; summer rainstorm events; and, fall low-flow

periods. Flows in each creek or river were measured at the same time as the water samples were taken.

Two additional water quality monitoring studies were conducted in 1999. A comparative sub-watershed study in which six sub-watersheds were chosen to be monitored intensively during the spring runoff, summer rainstorm, and fall low-flow periods. Two represented predominantly wildlife sub-watersheds, two sub-watersheds represented sub-watersheds that had high beef cattle densities within them (with limited presence of other types of agriculture), and the final two represented sub-watersheds that had high agriculture densities within them (included total cattle, pigs, horses, sheep and other stock). Sampling was conducted at the mouth of these creeks, prior to the confluence with the NSR. Each sub-watershed was sampled during spring runoff, summer rainstorm events, and during fall low-flow periods if the creek was flowing.

The second separate study in 1999 involved both upstream and downstream (upstream/downstream) monitoring of individual beef cattle operations. This was performed in three sub-watersheds in which water quality monitoring was performed upstream and downstream of beef cattle operators who were willing to participate in the study. Water samples were taken immediately before and after the farm location during spring runoff, summer rainstorm, and fall low-flow events.

1.3 Research Objectives

This study was designed to identify the primary sources of *Cryptosporidium* spp. and *Giardia* spp. in the NSR basin. The study was designed to investigate the loadings contributed to the NSR basin from sewage effluent (WWTP and STL), wildlife sources, beef cattle and high agriculture sources. The objectives included the following:

1. To determine if agricultural operations are contributors of *Cryptosporidium* spp. or *Giardia* spp. to surface water compared with wildlife and human sewage effluents; and,
2. To determine if watersheds with high cattle densities contribute greater levels of *Cryptosporidium* spp. or *Giardia* spp. to the NSR than watersheds predominated by wildlife.

The objective of the longitudinal study was to gain an understanding of the influence of the twenty major tributaries flowing into the NSR and their protozoan loading to the NSR. This study was to provide much needed information on the presence of protozoa in a watershed the size of the NSR basin.

The comparative sub-watershed study was designed to determine the *Cryptosporidium* spp. and *Giardia* spp. loading of predominately wildlife sub-watersheds in the basin as compared to sub-watersheds of high beef cattle versus high agriculture densities. The six study sub-watersheds were monitored intensively during spring runoff, summer rainstorm events and dry weather flows

in the 1999 study season. This study will provide information on the relative contributions from various land-uses in the study watersheds. It was hypothesized that the wildlife sub-watershed have the lowest loadings during all flow periods. The high agriculture sub-watershed was hypothesized to have the highest loadings during all flow periods.

The upstream/downstream study was initiated to determine the relative protozoan concentration differences immediately prior to and after a beef cattle operation. This study is intended to show the effect of a single operation on the presence of the protozoan pathogens in creeks flowing into the NSR.

At present, there is little information available on the concentrations of either *Cryptosporidium* spp. or *Giardia* spp. in WWTP and STL effluent. The WWTP and STL effluent monitoring study was designed to determine the relative contributions that these point sources make to the NSR.

Very little information exists on *Cryptosporidium* spp. and *Giardia* spp. in source and treated drinking water supplies in small, rural WTPs. Many small WTPs in Alberta do not test their finished water for the presence of these protozoa, and therefore it is essential to have an understanding of their ability to effectively treat the water and remove these protozoa. The WTP source and finished water monitoring study was designed to provide a basic understanding of the

concentrations of *Cryptosporidium* spp. and *Giardia* spp. in the source and treated water of rural WTPs

1.4 Outline of the Document

The remainder of this document is organized into five sections: review of literature; methodology; results and discussion; conclusions; and, recommendations. The review of the literature consists of an overview of watershed management strategies, *Cryptosporidium* spp. and *Giardia* spp., detection methods for parasites in water, fate and transport of the protozoa in natural waters, and water treatment reductions of *Cryptosporidium* spp. and *Giardia* spp. In the methodology section much of the discussion focuses on the sampling procedure and description of sampling locations. In the results and discussion section, results from the sampling program are presented and the results obtained from each set of analyses are discussed. The summary of the current study as well as recommendations for future study are presented in the conclusions and recommendations of this document.

2.0 REVIEW OF LITERATURE

This section provides an overview of the current literature as it pertains to the study. A brief description of watershed practices as they relate to source water protection is presented. An overview of the biology of *Cryptosporidium* spp. and *Giardia* spp. is then presented, along with current detection methods for these protozoa in water, water treatment and the protozoa, and the fate and transport of these protozoa. Finally, a brief discussion on watershed studies to date that have investigated the presence of *Cryptosporidium* spp. and *Giardia* spp. is presented.

2.1 Watershed Protection

Each day, there are increasing demands being placed on surface water and groundwater supplies for drinking water, industrial water supplies, and as a receiving body for waste disposal. The demands on and misuse of water supplies are contributing to a decline of water quality, and requirements of more complex treatment by water utilities to produce potable and safe drinking water. Treatment processes to reduce the risk of exposure to *Cryptosporidium* spp. and *Giardia* spp. are expensive and do not guarantee the safety of the water supply. These treatment processes must also respond quickly to changes in the water supply's quality. Poor quality surface water is not only a health risk, it is also aesthetically unpleasing, damaging to the natural aquatic biota and hinders recreational use.

Water utilities are now realizing the benefits of watershed protection, the prime goal of which is to protect the surface water from contamination, thereby reducing treatment requirements. Watershed protection is now viewed by many utilities as the first step in the treatment process. By managing the activities and discharges occurring in the watershed, the contaminant input into the water can be controlled or reduced, improving the water quality. It is far more economical, effective, and environmentally responsible to protect a watershed rather than allowing contamination to occur and then trying to clean it up.

In the past, monitoring programs were designed to focus on specific stretches of water, or a specific quality problem. A watershed approach is a more logical basis for managing a water resource, in which all of the stresses on water quality can be identified, prioritized, and addressed.

2.1.1 EPCOR's Watershed Protection Program

EPCOR recognizes the benefit of source water protection in safeguarding the water against sources of contamination such as the presence of *Cryptosporidium* spp. or *Giardia* spp. Source water protection is the first step in the multiple-barrier approach to drinking water treatment that EPCOR utilizes. By ensuring its source water is as clean as possible, a water utility helps to safeguard the health of its customers.

EPCOR began its watershed protection program in the early 1990s. At present, EPCOR's watershed protection goals include:

1. Acting as a resource and leader regarding water quality issues in the North Saskatchewan River Basin;
2. Forming partnerships to work cooperatively on watershed issues, including developing strategies to protect the watershed as a drinking water resource;
3. Monitoring water quality changes in the North Saskatchewan River and responding to emerging water quality issues in the basin; and,
4. Promoting strategies that will enhance water quality in the North Saskatchewan River Basin.

2.1.2 North Saskatchewan River Basin

The NSR originates at the Saskatchewan Glacier, located 500 km west and south of Edmonton in the Columbia Icefields of Banff National Park. The NSR is a major tributary in the Saskatchewan-Nelson river system, and the NSR basin is part of the larger Saskatchewan River Basin which flows through Alberta, Saskatchewan, and Manitoba into Hudson's Bay, draining 432 000 square kilometres (km^2) (Shaw 1994). The NSR basin upstream of Edmonton (Figure 1.) comprises 27 195 km^2 of land (Process Development Team 1992).

The river basin is mainly underlain by Paleozoic and Mesozoic strata, with a considerable depth of glacial till. Till is very erodable, as noted by the large and

steep river valley walls on outside bends of the river. The river bottom is mainly gravel to rubble. Near the banks, the bottom is more a sand and mud mix (Paterson 1975; Rutter 1982).

The NSR basin's watershed includes mountains, foothills, forest, muskeg and farmland. Much of the upstream watershed is uninhabited forest with little industrial or residential development, although there is a significant amount of agricultural land-use closer to the City of Edmonton. The basin upstream of Edmonton can be divided into two regions, the upper basin and the lower basin. The upper basin, west of Drayton Valley, is sparsely populated and remains primarily in its natural state, while the lower basin, also sparsely populated, supports a variety of land uses including: cropland; pasture; forestry; petroleum exploration and refining; coal-fired power plants; and several wastewater treatment facilities. Over 50 percent of the land around Edmonton is under cultivation, while west of Thorsby, there are more areas of rough pasture and wild-land (Process Development Team 1992). The 1996 census data indicates there were 491 903 cattle in the watershed.

The NSR is fed by the Brazeau, Clearwater, and Nordegg Rivers and numerous creeks including Modeste, Strawberry, and Rose Creeks. Before these join the NSR, these rivers and creeks flow through muskeg and forest areas. The Saskatchewan Glacier itself comprises 5% of the winter flow and 50% of the summer flow of the NSR. The Clearwater, Brazeau and Nordegg Rivers

comprise 6%, 36% and <1% of the winter flow respectively, and 13%, 30% and 3% of the summer flows, respectively (Hrudey 1986). During most of the year, the tributary creeks in the lower basin do not contribute significantly to the flow (less than 20%) in the NSR (Process Development Team 1992). However, during spring runoff in the lower basin and severe summer storms, the flow in these creeks can increase drastically, up to 100 times greater than the base flow, while the flow in the NSR may only increase by up to approximately five times the normal flow. When this occurs, the creeks can contribute 50% of the flow in the NSR at Edmonton (Process Development Team 1992). The increased flows in the creeks can flush material and waste that has accumulated on the banks and land around the creeks into the creeks.

There are two dams, located upstream of Edmonton, owned and operated by TransAlta Utilities: the Brazeau on the Brazeau River constructed in 1963; and, the Big Horn on the NSR constructed in 1972. The summer flows at Edmonton average 210 m^3/s (Process Development Team 1992). The winter flows range from 95 m^3/s to 245 m^3/s, however, TransAlta Utilities attempts to maintain the winter flows between 90 m^3/s and 110 m^3/s (Ray 1991).

2.2 *Cryptosporidium* spp.

Cryptosporidium spp. is taxonomically described as a coccidian protozoan. It has been placed in the phylum *Apicomplexa*, the order *Eucoccidioridia*, and the family *Cryptosporidiiae*. *Cryptosporidium* spp. was first described by Tyzzer

(1907) as found in the gastric mucosa of mice. Four species of *Cryptosporidium* spp. are recognized: *C. parvum* and *C. muris*, found in mammals, and *C. baileyi* and *C. meleagridis* found in birds (Levine 1984). Of these species, *Cryptosporidium parvum* is the major species responsible for clinical illness in humans and animal. Contamination occurs when the uninfected individual ingests the environmentally stable oocyst, which is excreted in the feces of infected individuals.

Cryptosporidium spp. was first recognized as a pathogen during an outbreak of diarrhea in a turkey flock in 1955, after which it was identified as an infectious agent in cattle and sheep. (Rose 1988). In humans, *Cryptosporidium* spp. infections were first identified with immunocompromised individuals and were brought to the attention of the medical community with the occurrence of acquired immune deficiency syndrome (AIDS). *Cryptosporidium* spp. was conclusively recognized as an agent of human waterborne disease in 1987 (Rose 1988; Hayes 1989)

Cryptosporidium spp. in humans completes its life cycle in the gastrointestinal tract, and being an obligate parasite, it can replicate only within its host. *Cryptosporidium* spp. oocysts are spherical or slightly ovoid in shape (in C. *parvum*, about 3 to 5 μm in diameter) and are shed in numbers of up to 10^5 to 10^7 oocysts per gram in calf feces. The life cycle of *C. parvum* begins with ingestion of the infectious stage, the oocyst, which releases four sporozoites after

excystation. This stage initiates infection within the epithelial cells of the gastrointestinal tract. The sporozoite differentiates into the trophozoite, which undergoes asexual multiplication to form type I meronts and then merozoites, which may infect new host cells. Merozoites from type II meronts produce microgametocytes and macrogametocytes, which undergo sexual reproduction to form the oocyst, which is then excreted with the feces (Rose 1988). The oocysts are immediately infective upon excretion.

Cryptosporidium spp. appears to be ubiquitous, meaning it is found in both domestic animals, (cattle, sheep, swine, goats, dogs, and cats) and wild animals (deer, raccoon, foxes, coyotes, beavers, muskrats, rabbits, and squirrels). It is now apparent that many mammalian isolates are able to cause infection in other mammals (Rose 1988). In a study reviewing the cross transmission of *Cryptosporidium* spp., Fayer and Ungar (1986) found that isolates from cats, cattle, and pigs are able to initiate infection in humans. As well, they showed that human isolates have produced infection in cats, dogs, cattle, goats, sheep, pigs, mice, and rats. Fayer and Ungar (1986) and Rose (1988) reported that transmission between avions and mammals has not been successful.

Many mammals may serve as reservoirs of infection for humans. This cross-species transmission increases the potential for waterborne disease because animals, in addition to humans, may also contaminate water sources. The most significant factor influencing the potential for waterborne transmission of

Cryptosporidium spp., however, is the fecal-oral route of transmission from host to host by its environmentally stable oocyst (Rose 1988).

Early investigations have found that *Cryptosporidium* spp. oocysts are more resistant to hospital disinfectants than are other enteric bacteria (Campbell et al, 1982). Peeters et al. (1989) reported that an ozone dose of 1.11 mg/L for 6 minutes could inactivate *Cryptosporidium* spp. > 90 percent and that an ozone dose of 2.27 mg/L for 8 min could kill oocysts > 99.8 percent (no temperature or pH was reported). Peeters et al. (1989) also reported that 15-min contact with 0.4 mg/L chlorine dioxide could significantly reduce oocyst infectivity, although some oocysts remained viable. In contrast, Korich et al. (1990) found that 1.3 mg/L chlorine dioxide yielded a >90 percent oocyst inactivation after 60-min contact time. The researchers showed that >90 percent inactivation was achieved by treating oocysts with 1 mg/L ozone for 5 min (25°C, pH 7.0). Korich et al. (1990), also found that 80 mg/L of free chlorine or monochloramine required 90 minutes to produce 90 percent oocyst inactivation. Korich concluded that current disinfection practices would do little to inactivate waterborne *Cryptosporidium* spp. The major barrier to *Cryptosporidium* spp. reduction in water treatment is filtration. Water treatment and *Cryptosporidium* spp. and *Giardia* spp. are discussed in detail in section 2.5 of this document.

Cryptosporidium spp. appear to be widely distributed in the aquatic environment. Musial et al. (1987) estimated that *Crytosporidium* spp. levels in secondary

sewage effluents ranged between 5 and 17 oocysts/L. Madore et al. (1987) found that *Cryptosporidium* spp. levels averaged 5 180 oocysts/L in raw sewage and 1 063 oocyst/L in treated wastewater. Ongerth and Stibbs (1987) estimated that the levels of *Cryptosporidium* spp. in several western Washington and California rivers ranged between 2 and 112 oocysts/L. Rose (1988) found *Cryptosporidium* spp. levels ranged between 0.91 and 28 oocysts/L (geometric means) in various waters throughout the western United States.

2.3 *Giardia* spp.

Giardia spp. are flagellate intestinal protozoa that cause the waterborne disease giardiasis. In human beings and some animals, clinical signs of giardiasis include acute or chronic diarrhea, abdominal pain, dehydration, weight loss, or reduction in weight gain (Adam 1991). *Giardia* spp. are one of the most commonly identified intestinal pathogens in human beings and animals throughout the world (Adam 1991). *Giardia lamblia* , also known as *G. duodenalis* or *G. intestinalis*, was first documented as a causative agent of waterborne intestinal disease in the United States in 1966. There were 92 outbreaks during the period of 1971-1985 attributed to *Giardia* spp. which affected over 24 000 individuals (Craun 1997). The City of Edmonton had a *Giardia* spp. outbreak between December 1982 and April 1983, with 895 positive reports of giardiasis (Health and Welfare Canada 1983). At this time, the WTPs in Edmonton were not testing their source or finished water for the presence of *Giardia* spp. King (1989) performed a time-space relationship model on the reported cases of giardiasis in the 1983 outbreak which strongly imply that the

source of the *Giardia* spp. was treated water. In July, 1983, it became mandatory for physicians in Alberta to report cases of giardiasis to public health authorities to facilitate early detection of future outbreaks.

The organism is transmitted in the cyst stage via direct fecal-oral route, or through waterborne transmission (Buret 1990). Infection is acquired after infective cysts are ingested. The cysts then excyst within the duodenum, releasing trophozoites that multiply and colonize the small intestine.

Giardia duodenalis has been found in humans, beavers, muskrat, mule deer, domestic sheep, cattle, elk, coyotes, dogs, cats, horses, moose, and a number of small wild and laboratory rodents (Jakubowski 1979). Some investigators considered the parasite found in humans (*G. lamblia*) to be host-specific, but the majority of research performed to date questions this assumption. Faubert (1988) suggests that giardiasis may be a zoonosis and possibly a zooanthroponsis. *Giardia duodenalis* of human origin can infect other animals (Belosevic 1983). The parasite has been successfully transmitted from humans to beavers (Davis 1979; Erlandsen 1988), beaver to human (Davis 1979), human to muskrat and from muskrat to dogs and cats, mule deer to humans, and from humans to a number of laboratory rodents (Davis 1979; Hibler 1990). While the parasite has been successfully cross-transmitted, thus proving it is not host-specific, not every source from any given animal will cross-transmit every time

the effort is made, indicating there may be strains that do not readily adapt to a new host (Davis 1979).

Giardia spp. form environmentally resistant cysts that allow the extended survival of the parasite in surface and treated drinking water. The cysts are characteristically oval or ellipsoid and slightly asymmetric in shape, ranging from 8 to 14 μm long and from 7 to 10 μm wide (Lin 1985; Garcia 1987). Rendtorff and Holt (1954), reported that G. *lamblia* cysts survived in dechlorinated tap water and remained infective for 16 days, the longest period tested. Bingham et al. (1979), reported 100 percent cyst inactivation after 6 days at 37 °C, 25 days at 21 °C, and 77 days at 4 °C in dechlorinated tap water. DeRegnier et al. (1989) showed increased *Giardia* spp. survival in various water samples correlated with decreased water temperature.

At present, concern is increasing that *Giardia* spp. infections in both wild and domestic animals pose a serious zoonotic threat to human beings (Buret 1990; Adam 1991). Domestic animals, especially domestic ruminants, which are infected are a cause of concern due to the potential contamination of surface water and groundwater. Contamination of these waters may occur during spring runoff or rainstorm events when the pasture, covered with feces, is flushed (Olson 1995). Waterborne giardiasis in human beings has been attributed to pasture runoff, which leads to drinking water contamination (Weniger 1983). LeChevallier (1991) has reported that large numbers of *Giardia* spp. cysts in a

municipal water supply have been found to be associated with agricultural effluent.

It was thought that *Giardia* spp. outbreaks primarily occurred in mountainous areas. However, a number of epidemiological studies have shown that the occurrence of G. *lamblia* is widespread, with infection rates among individuals in North America ranging from 1.5 to 22 percent (Healy 1979). Schmidt (1977) observes that a moderate infection may contain 300 million parasite cysts. It is not surprising, therefore, that *Giardia* spp. have been routinely recovered from sewage and in water receiving sewage treatment plant effluents (Sykora 1986; Rose 1988). *Giardia* spp. have previously been reported to be present in 10 to 28 percent of the lakes, rivers, or creeks tested from 301 municipal sites in 28 states between 1979 and 1986 (Hibler 1988). Levels of cyst contamination have ranged from 0.003 to 6 cysts/L (Akin 1986; Rose 1986).

2.4 Detection Methods for *Cryptosporidium* spp. and *Giardia* spp. in Water and Effluent Samples

In 1975, the Centers for Disease Control (CDC) used a sand swimming pool filter to detect *Giardia* spp. in raw water following the Rome, NY outbreak. This was the first time that *Giardia* spp. cysts were successfully detected in contaminated water samples, and therefore provided evidence for waterborne transmission of *Giardia* spp. (Shaw 1977). The US Environmental Protection Agency (USEPA) Health Effects Research Laboratory developed a monitoring technique, which successfully detected cysts in raw and distributed water of the Camas, WA

system in 1976 (Jakubowski 1979). Recommended modifications to the USEPA method were made by participants at a workshop in 1980. These modifications were incorporated into the reference method published in the sixteenth edition of *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, 1998).

Methods for detection of protozoa in environmental samples evolved partially from those used for *Giardia* spp. and from those used in the clinical laboratory (Rose 1988). Cysts have been concentrated using polypropylene filters (Jakubowski 1984), polycarbonate filters (Ongerth 1987), tangential flow filtration (Isaac-Renton 1986) and electronegative filters (Payment 1989). Clarification of the sample has been achieved using zinc-sulfate, sucrose, potassium citrate, and Percoll-sucrose gradients (Jakubowski 1979; Jakubowski 1984; Rose 1988). *Giardia* spp. have been detected in samples using stains, including Lugol's iodine and trichrome (Jakubowski 1979; Spaulding 1983), and by immunofluorescence antibody (IFA) techniques (Riggs 1984; Sauch 1985; Sterling 1988). Methods for filtration, elution, clarification, and detection of *Cryptosporidium* spp. in water are similar to those for *Giardia* spp. (Rose 1985; Musial 1987; Ongerth 1987; Rose 1988).

Two similar systems have evolved that rely on concentration of the (oo)cysts from water using filters. The method developed by Ongerth and Stibbs (Ongerth 1987) employed a 293-mm polycarbonate membrane filter. The second method

(Musial 1987) used a 250-mm (10-in) polypropylene cartridge filter (1.0-μm pore size) for concentration of the oocysts from water. This system has an advantage over the polycarbonate system in that it can be easily transported to the sampling site, and large volumes of water can be processed. A disadvantage is the elution procedure. The cartridge filter was processed with 6 L of a 0.1 percent distilled water solution (Tween 80) by backflushing, cutting apart, and washing the filter. Thus it was necessary to concentrate 6 L of the eluent to a pellet using centrifugation, in contrast to approximately 300 mL when using the membrane filter method (Rose 1988).

The cartridge system used sucrose (1.24 g/mL) flotation to clarify the sample. High recoveries were achieved when 0.1 percent distilled water solution (Tween 80) and 1 percent sodium dodecyl sulfate were used with the sample. (Oo)cysts were detected on a glass slide (or hemacytometer) using a monoclonal antibody and epifluorescent microscopy (Rose 1989).

Further development of the cartridge filter system (Rose 1986) has included (1) decreasing the eluent volume to 2 700 mL, (2) improving clarification using sucrose at specific gravities of 1.24 and 1.17 g/mL, and (3) using a cellulose nitrate filtration membrane in conjunction with a monoclonal antibody for oocyst detection (Rose 1989).

The procedures of Sauch (1985) and Musial et al. (1987) were combined to simultaneously detect *Cryptosporidium* spp. and *Giardia* spp. in water supplies (LeChevallier 1990). The combined IFA procedures recovered an average of 74.1 percent of *Giardia* spp. cysts added to river water concentrates, whereas the reference technique (zinc flotation/Lugol's iodine) recovered only 5.9 percent of the cysts. Recovery of *Cryptosporidium* spp. oocysts by the IFA technique averaged 41 percent. Comparison of the IFA and zinc flotation/Lugol's iodine methods for recovery of *Giardia* spp. from natural water samples showed that the IFA procedure recovered between 1.5 and 40 times more cysts than the zinc-sulfate technique (LeChevallier 1991).

The Information Collection Rule (ICR) method for determining concentrations of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in water was developed in 1995 as the standard method (USEPA 1995). Problems with the method are well documented. They include low and highly variable recoveries which are influenced by the volume sampled and water quality (high turbidity, suspended solids, organic content, chlorine and other disinfectants), high false-positive and -negative rates, and poor accuracy (Rose 1986; Ongerth 1987). In addition to poor recoveries, the current techniques have a number of other limitations. In all previously reported studies, no differentiation has been made between bird or mammal oocysts (Sterling 1986; Stibbs 1986; Garcia 1987) (Fayer and Ungar 1986). The most significant limitation is probably the inability to determine (oo)cyst viability (Rose 1988).

A draft for a new method of *Cryptosporidium* spp. quantification in water, Method 1622 was published in 1997 (USEPA 1997). This method is a significant improvement over the ICR method however, it does not allow the simultaneous identification of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts. Clancy (1999) reports that with Method 1622's two-laboratory validation, the overall recovery is about 35 percent with 100-oocyst spike dosage. No nondetects were reported in the 32 natural samples analyzed, and the entire 10 L sample was analyzed on a single well slide. Elimination of sub-sample analysis in method 1622 reduces the possibility of uneven oocyst recovery that can lead to over- or underestimation of total numbers in a sample. USEPA's 13-laboratory round-robin collaborative trial of method 1622 showed that it is robust, with an overall recovery of 43 percent (Clancy 1999).

At present, there is no standard recognized method for the identification of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts from sewage effluent. EPCOR Water Services Laboratory uses a continuous-flow centrifuge system (CCS) for the determination of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in sewage effluent. (Goatcher 1995). This CCS provides a quantitative indication of the level of the environmentally resistant stages of both *Cryptosporidium* spp. and *Giardia* spp. in the sewage effluent samples. The laboratory reports that this CCS can be used as an alternative to the cartridge filter method used in the ICR method for both raw water and finished drinking water samples. *Standard Methods* points out that recovery of cysts and oocysts

may be higher in some water samples using the CCS (American Public Health Association, 1998), and results to date from the EPCOR Water Services Laboratory show a higher percent recovery using the CCS over the ICR.

Concentrations of oocysts or cysts found in water samples may be adjusted mathematically to reflect a more accurate concentration based on recovery method efficiencies. This approach should only be used when seeded recoveries are determined concurrently with each sample tested, otherwise accurate determinations cannot be made. Recoveries vary even under controlled laboratory conditions, and characteristics of the water sample at the time of collection will influence the recovery rate (Rose 1988).

2.5 Water Treatment Reduction of *Cryptosporidium* spp. and *Giardia* spp.

Waterborne diseases are either increasing or are increasingly reported in Canada and the United States (Craun 1977) and sharpened public awareness has increased pressure on the water treatment industry to improve product quality and safety (van Roodselaar 1998). *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts have been detected in raw waters varying from contaminated lakes and highly turbid, coloured rivers to clear mountain streams. The wide presence of these protozoa is attributed to the variety of hosts available for the transmission of these organisms.

Potable water has never been intended to be sterile. Instead, two objectives are set, the first being the ability to treat the water so as to reduce the health risk to the lowest extent possible. The second objective is for taste and odour of the treated water to be acceptable to the end consumer (Geldreich 1996). Risk reduction is achieved by the removal of human pathogens, including viruses, bacteria, protozoa, helminths, and fungi. At present, water utilities use a wide range of treatment options to reduce the pathogen level, including: sedimentation, coagulation/flocculation, filtration, and chemical microorganism reduction. The microbiological reduction process includes: heat, chlorine, ozone, extreme pH's, iodine, and ultra violet radiation.

To date, the primary barrier against waterborne *Cryptosporidium* spp. and *Giardia* spp. is physical removal of the (oo)cysts through coagulation, sedimentation and filtration. Most waterborne outbreaks have been associated with problems with one of these processes (Rose et al. 1997). For *Giardia* spp., high concentration times time exposures can be effective and for both *Cryptosporidium* spp. and *Giardia* spp., ozone is an effective disinfectant (Finch et al. 1994; Finch et al. 1992; Finch et al. 1997)

The water utilities' emphasis should be on establishing those conditions which provide adequate levels of protection against *Cryptosporidium* spp. and *Giardia* spp. (oo)cysts. Effectiveness of more than one process in reducing *Cryptosporidium* spp. and *Giardia* spp. (oo)cyst risk in the treated water, either

through removal or inactivation, results in a multi-barrier screen. Some plants may depend on only one treatment barrier, causing risk of *Cryptosporidium* spp. or *Giardia* spp. penetration if this barrier fails or if the effectiveness of this barrier is overestimated. As a result, detailed information on each barrier, and the net impact of multiple barrier operation, is necessary for water utilities to properly assess the risk associated with their finished water. The first step in the multi-barrier approach to water treatment is often seen as watershed protection. Protected watersheds generally have lower (oo)cyst levels than sites receiving agricultural, sewage, or urban runoff (Rose et al. 1997). Limiting these activities in a watershed might help reduce the burden on the water treatment process (Glicker 1990), but storm events that wash fecal material into receiving streams, animal migration, or epizootic infections may create peaks in the (oo)cyst densities as well. No studies to date have quantified the relative contribution of various sources of contamination, the watershed manager therefore is left to guess at the significance of sources of contamination.

To protect and control its watershed, a utility must own its impoundment system and land reserves. As few utilities are in this position, but most utilities have limited or no watershed protection capabilities. All potential sources of contamination should be known. A systematic approach enables identification of sources of protozoa and conditions that could lead to treatment challenges. The knowledge of potential sources of contamination in a watershed enables water

utilities to make decisions more confidently about protection of source waters (Crockett 1997).

2.6 Fate and Transport of *Cryptosporidium* spp. and *Giardia* spp.

At present, there is very little information about the fate and transport of *Cryptosporidium* spp. and *Giardia* spp. in natural waters. Many authors have indicated that there is a need for expanded research into (oo)cyst fate in streams and impoundments, and the concentration of (oo)cysts in sewage effluent (Walker 1999).

Transport of infectious (oo)cysts from the source of contamination to hosts such as recreational users of surface water, drinking water treatment intake withdrawal, and livestock and wildlife watering locations, is governed by several hydrodynamic, chemical, and biological factors; i.e., water flow, attachment of freely suspended (oo)cysts to particles, sedimentation and resuspension of free and attached (oo)cysts, and survival of (oo)cysts (Medema 1997).

Cryptosporidium spp. and *Giardia* spp. (oo)cysts can remain viable for several months in water between 4 and 10 °C (Medema 1997). The inactivation rate depends on the presence of an autochthonous microflora (predation, or structural or metabolic injury by exoenzymes), temperature, and sunlight intensity (Robertson 1992; Chauret 1995; Medema 1997).

Medema (1998) observed sedimentation velocities are very low and will probably not result in significant sedimentation in natural aquatic habitats. Turbulence caused by water flow, wind, temperature, and movements of aquatic organisms is more likely to influence the movements of (oo)cysts in water than gravitational settling. Water flow, or bulk transport, therefore, is the dominant force in the transport of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in water and wastewater.

In stagnant waters, free (oo)cysts are transported by advection and slowly settle to the sediment. Stagnant water may be found in natural environments where the water flow is low (lakes and slow-flowing streams and rivers in summer), as well as in impoundments and settling tanks, both used in water and sewage treatment processes. The sedimentation of (oo)cysts in water follows Stokes' Law, indicating that the sedimentation velocity depends on particle size, difference in density between particles and water, and the viscosity of water. Theoretical calculations by Ives (1990) indicate that the sedimentation velocities of single *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in stagnant water are low, at 0.5 and 5.5 μm/s, respectively. In a water impoundment, (oo)cysts require more than a year to them to settle to the bottom of a 20 m deep impoundment (Badenoch et al. 1990).

In wastewater and surface water environments where protozoan concentrations are high, a proportion of the (oo)cysts in surface water may attach to particles

such as clay, sand, plankton, algae, and (bio)flocs. The sedimentation behavior of attached (oo)cysts are influenced by the characteristics (size and density) of these particles. Previous studies (Sauch 1985; LeChevallier 1991; Vesey 1993; Nieminski 1995) used sampling techniques (filtration and flocculation) that do not allow discrimination between free and attached (oo)cysts; therefore little information on the behavior of attached (oo)cysts exists.

(Oo)cysts have a high survivability and settling may result in the accumulation of (oo)cysts in aquatic sediments. Disturbance of these sediments, by for instance bathers, or increased water flow, may result in concentration peaks in the water yielding a relatively high risk of exposure and breakthrough for drinking water treatment systems.

Discharges from activated sludge treatment systems of sewage are important sources of surface water contamination of *Cryptosporidium* spp. and *Giardia* spp. *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts were shown to rapidly attach to particles from secondary effluent of a biological wastewater treatment plant. Medema (1999) found that approximately 35% of both oocysts and cysts almost instantly attached and as much as approximately 70% attachment was attained after 24 hours.

2.7 Watershed Studies

At present, very few watershed-scale studies have investigated the presence of *Cryptosporidium* spp. and *Giardia* spp. Most studies to date have either focused on one river or creek in particular, or have gathered samples for analysis from different locations within a country for analysis. To properly assess the presence of the protozoan in a watershed and the risk of contamination, a thorough knowledge of the sources of contamination is required. There are even fewer studies that have attempted to gather and interpret data from such a range of sources within one watershed. This section describes watershed investigations on the presence of *Cryptosporidium* spp. and *Giardia* spp. within Alberta, Canada, United States and throughout World.

2.7.1 Studies Within Alberta

To date, there has been no other watershed scale research project focussing on the relationship between *Cryptosporidium* spp. and *Giardia* spp. concentrations in surface water and sources in Alberta.

EPCOR has conducted preliminary surveys of the Strawberry Creek sub-watersheds in the NSR basin for *Cryptosporidium* spp. and *Giardia* spp. The study comprised an inventory of the watershed physical characteristics, land usage and water quality; an assessment of contaminant sources throughout the basin; and an evaluation of Strawberry Creek's contribution to the water quality of the NSR (Whitehead, 1997). EPCOR also maintains a rigorous monitoring

program for *Cryptosporidium* spp., *Giardia* spp., and other water quality parameters (e.g. taste, odour, and colour) at both water treatment plants at Edmonton.

Presently, there is a project supported by the American Water Works Association (AWWA) by researchers at the Northern Alberta Provincial Laboratory for Public Health, University of Alberta, Capital Health Authority and EPCOR to develop a guidance manual for waterborne disease outbreak detection for North America. The ability to detect waterborne disease outbreaks in a population would be greatly enhanced by determining the sources of waterborne parasites in a watershed. Therefore, the current research reported herein would complement and complete the effort to design a public health protection program to minimize the risk of waterborne disease.

2.7.2 Studies Within Canada

Researchers in British Columbia (Ong 1996) at the University of British Columbia, and the Ministry of Health have studied *Cryptosporidium* spp. and *Giardia* spp. levels in surface water at a watershed-scale, however *Cryptosporidium* spp. sampling was incomplete. This study investigated parasite prevalence in cattle found in the watershed combined with water monitoring for protozoa. This study limited potential sources of contamination to cattle in the watershed, and did not investigate any other potential sources of contamination.

2.7.3 Studies Within North America

There are a limited number of watershed-scale studies focused on the presence and potential sources of *Cryptosporidium* spp. and *Giardia* spp. in the United States and very few attempt to identify multiple sources within a watershed.

Crockett and Haas (1997) undertook a thorough investigation of Philadelphia's watershed to understand the sources, fate and transport of protozoan in its watershed. During this study, a database was compiled with information regarding occurrence of *Cryptosporidium* spp. and *Giardia* spp. in the United States. The database was based on general watershed type and cannot be used to specifically classify the sources of protozoa in other watersheds.

Ongerth (1995) undertook a study to investigate the presence of *Giardia* spp. in two different watersheds in Washington, with varying degrees of use. This study also investigated the presence of *Giardia* spp. in selected animal species within the two study watersheds. However, the presence of *Cryptosporidium* spp. was not investigated. Ongerth found that *Giardia* spp. was present to a more substantial degree and a greater concentration in the watershed that had more human activity, than the one that did not.

Sischo et al. (2000) studied the prevalence and risk factors for shedding of *Cryptosporidium* spp. by dairy cattle and calves and the prevalence and risk factors for *Cryptosporidium* spp. in surface waters associated with dairy farms in

a well-defined watershed in the northeastern United States. Ninety-one percent of the dairy farms in their study had *Cryptosporidium* spp. on their premises. Fifteen percent of the sampled calves 0 to 3 weeks of age were shedding *Cryptosporidium* spp. The single risk factor for detecting *Cryptosporidium* spp. in surface water was increasing frequency of spreading of manure on fields. Only *Cryptosporidium* spp. was investigated, and not *Giardia* spp. The researchers attempted to collect upstream/downstream samples, and found that the prevalence of *Cryptosporidium* spp. was greater upstream than downstream of contributing farms. The study was conducted for six months only and it used a variation of the USEPA Method 1622 (1997) where they collected only 4 L or 8 L of water, not the recommended 10 L for filtration at the lab.

2.7.4 Studies Elsewhere in the World

Hsu (1999) investigated the presence of *Cryptosporidium* spp. and *Giardia* spp. in the Kau-Ping River and its watershed in Southern Taiwan. They collected 32 fecal samples and 13 water samples from the river and its watershed to test for the presence of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts. The detection methods used were immunofluorescence assay and enzyme-linked immunosorbent assay for water and fecal specimens, respectively. They found that seven out of eight samples collected from raw water samples showed the presence of cysts, while six out of eight raw water samples contained oocysts. As well, *Cryptosporidium* spp. was present in 40% of the treated water samples, while *Giardia* spp. occurred in all of them.

3.0 METHODOLOGY

This section describes the sampling procedures that were used to collect the protozoan, microbiological, chemical and physical parameters of the water. As well, the sampling procedure for sewage effluent is also described. The sampling locations are described in detail, and summarized in both a figure, and tables. The laboratory analysis procedures, together with quality control and quality analysis are discussed at the end of this section.

3.1 Sampling Procedures

At the time the project was defined (1997), the methods for sample collection and simultaneous detection of *Giardia* spp. and *Cryptosporidium* spp. had been described by the Information Collection Rule (ICR) (LeChevallier 1990; LeChevallier 1991; USEPA 1995; USEPA 1995). Expected recovery efficiencies using this method were 42% for *Cryptosporidium* spp. and 48% for *Giardia* spp. in raw water samples containing less than 150 nephelometric turbidity units (LeChevallier 1991).

The Method 1622 for *Cryptosporidium* spp. detection was not published in draft format until December 1997, and was not well know to the laboratory performing the analysis for this study. Method 1622 also did not allow the simultaneous quantification of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts. As well, no study performed to date has used the Method 1622 for protozoan analysis,

and using this method would make comparisons between studies difficult. It was for these reasons that the ICR method was used for raw surface water and finished drinking water samples (USEPA 1995). This method is described in detail in Appendix A. The sewage effluent samples were processed using the continuous-flow centrifuge system method, developed by EPCOR Water Services Inc. (Goatcher 1995) and is also described in detail in Appendix A.

Raw river water and finished drinking water samples for protozoan analysis were collected according to the ICR method (USEPA 1995). Large volume source and treated water samples were filtered in the field (Figure 3.1), whereas sewage effluent was collected in 20 L carboy containers and filtered in the laboratory. All water and effluent analyses, paired with turbidity samples, were carried out at the EPCOR Water Services Inc. Microbiology Laboratory (Rossdale Water Treatment Plant, Edmonton, Alberta).

Samples for chemical and bacteriological analyses (Table 3.1) were collected as grab samples directly into sample bottles from the stream, raw water source or effluent. Except for bacteriological samples, bottles were pre-rinsed with sample water before filling. In 1999, sodium and chloride were also measured in raw water and sewage effluent from plants upstream of Edmonton so that mass balances could be performed.

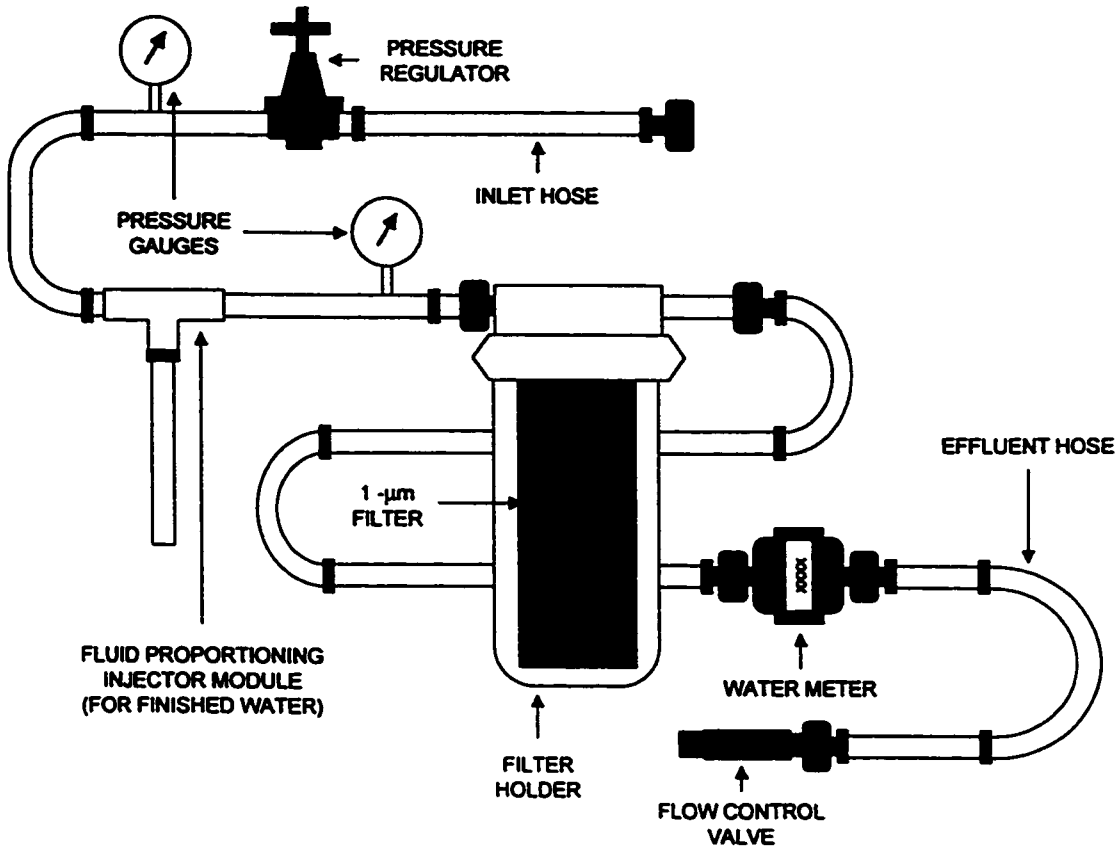

Figure 3.1. Field Sampling Apparatus for Collection of Protozoan Samples (After USEPA 1995)

Municipal sewage effluent, from WWTPs and STLs, and source and treated drinking water from WTPs, in the NSR basin, west of and including the City of Edmonton (Figure 3.2) were monitored from March/April 1998 to December 1999. Fifteen (15) of seventeen (17) sewage treatment facilities were monitored during the study period, including four mechanical sewage plants that discharge continuously and eleven sewage lagoons that periodically release sewage effluent into the NSR basin or tributaries that drain into the river. Two STLs were not sampled during the study period because the sampling crews were not notified that the lagoons were discharging. The sewage treatment facilities

included in the study are described in detail in section 3.1.2 and 3.1.3 of this document.

Table 3.1 Chemical and Bacteriological Variables Measured in Water Samples From Raw and Treated Drinking Water and Sewage Effluents in the North Saskatchewan River Basin 1998-1999

Microbiological	Chemical	Field
Cryptosporidium spp. spp. *Giardia* spp. Fecal coliform bacteria *E. coli* *Camplyobacter* spp.	Total suspended solids Turbidity True colour Total organic carbon Total phosphorus Dissolved phosphorus Total kjeldahl nitrogen Ammonia-nitrogen Nitrite+nitrate-nitrogen Sodium Chloride	Flow volume pH

Water samples were collected from 50 sites in the NSR basin upstream of, and including, the City of Edmonton, Alberta (Figure 3.2). Raw water samples (approximately 100 L) were collected from 29 creeks and river sampling sites. Finished water samples (1 000 L) as well as source water samples were collected from 6 WTP and sewage effluent samples (20 L) were collected from 4 WWTPs and 11 STLs.

Raw water samples were collected using a battery-powered water pump (Proven Pony Pump, model #365, Los Angeles, California) or a pressurized tap and filtered through a 254 mm yarn wound polypropylene filters having a nominal porosity of 1μm (For filter and filter holder use: a) 254 mm long 1 μm nominal porosity, yarn-wound polypropylene cartridge Commercial honeycomb filter tube

(M39R10A; Commercial Filter Parker Hannifin Corp., P.O. Box 1300, Lebanon. IN) with a Commercial LT-10 filter holder; or b) a 254 mm long 1 µm nominal porosity Filterite polypropylene cartridge (U1A10U; Filterite Corporation, Timmonium, MD), with a Filterite LMO10U-3/4 filter holder; or c) Ametek polypropylene cartridge (Cat. No. 155429-03, Filtrex Systems, Coquitlam, B.C.) with Ametek (Cat. No. 158007) filter holder). Sampling locations in each river were about 1 to 2 metres from the bank, where the water was approximately 1 m deep. Water samples were collected from mid-depth. Care was taken to avoid material floating at the surface and not to disturb bottom sediments. Flow rates were adjusted to 4 L/min, measured using any of the following: 1) ABB flow meter, model C700 TP 5/8 x ½, Ocala, Florida; or 2) Kent meter, model C700 5/8; or 3) neptune 5/8, trident 8; or 4) neptune 5/8 T-10 (trident), flowmeters placed downstream of the filter. Flow pressure never exceeded 103.4 kPa. Approximate volumes of 100 L for surface waters (31 of 275 river water samples had less than 100 L filtered [min 8 L, max 93 L] due to the extreme turbidity of the raw water during summer storm events), and 1000 L for treated drinking water were filtered (Rose 1988; USEPA 1995; Isaac-Renton 1996). Treated drinking water had a 2% thiosulfate solution added during pumping at a rate of 10 mL/min, to dechlorinate the water. An attachment on the pressure gauge/regulator unit allowed the thiosulfate to be added via venturi flow method. A 20 L carboy was filled with treated sewage effluent, which was processed at EPCOR Water Services, Rossdale Water Treatment Plant, Edmonton, Alberta, using their own in-house standard operating procedure. Separate collection

systems were used for raw, finished water samples and treated sewage effluent samples. Between samples, the units were flushed with 100 L of sample water to dislodge any attached organisms (Ong 1996). Each night, the entire filtering apparatus, including the pony pumps and flowmeters were flushed with water and Neutrad (pH~7.0, phosphate free, highly concentrated scrubbing solution) followed by at least 100 L of warm tap water. If the filter units were dirty, they were scrubbed separately as well.

Effluent samples were collected approximately every other month from continuously discharging facilities and during the time of discharge for each sewage lagoon that discharged during the study period. An effort was made to sample during the middle of the discharge period. Similarly, samples for source and treated water from three municipal drinking water treatment plants were collected approximately every other month from March 1998 to December 1999. Raw water from one additional plant, in the small town of Thorsby, was also sampled occasionally. All four drinking water treatment plants upstream of the City of Edmonton (Rocky Mountain House, Drayton Valley, Thorsby and Devon) use the NSR as a source.

In addition to samples taken for this project, an extensive data base of source water protozoan data was available from the two WTPs in the City of Edmonton (the EL Smith WTP and the Rossdale WTP). Finished water protozoan

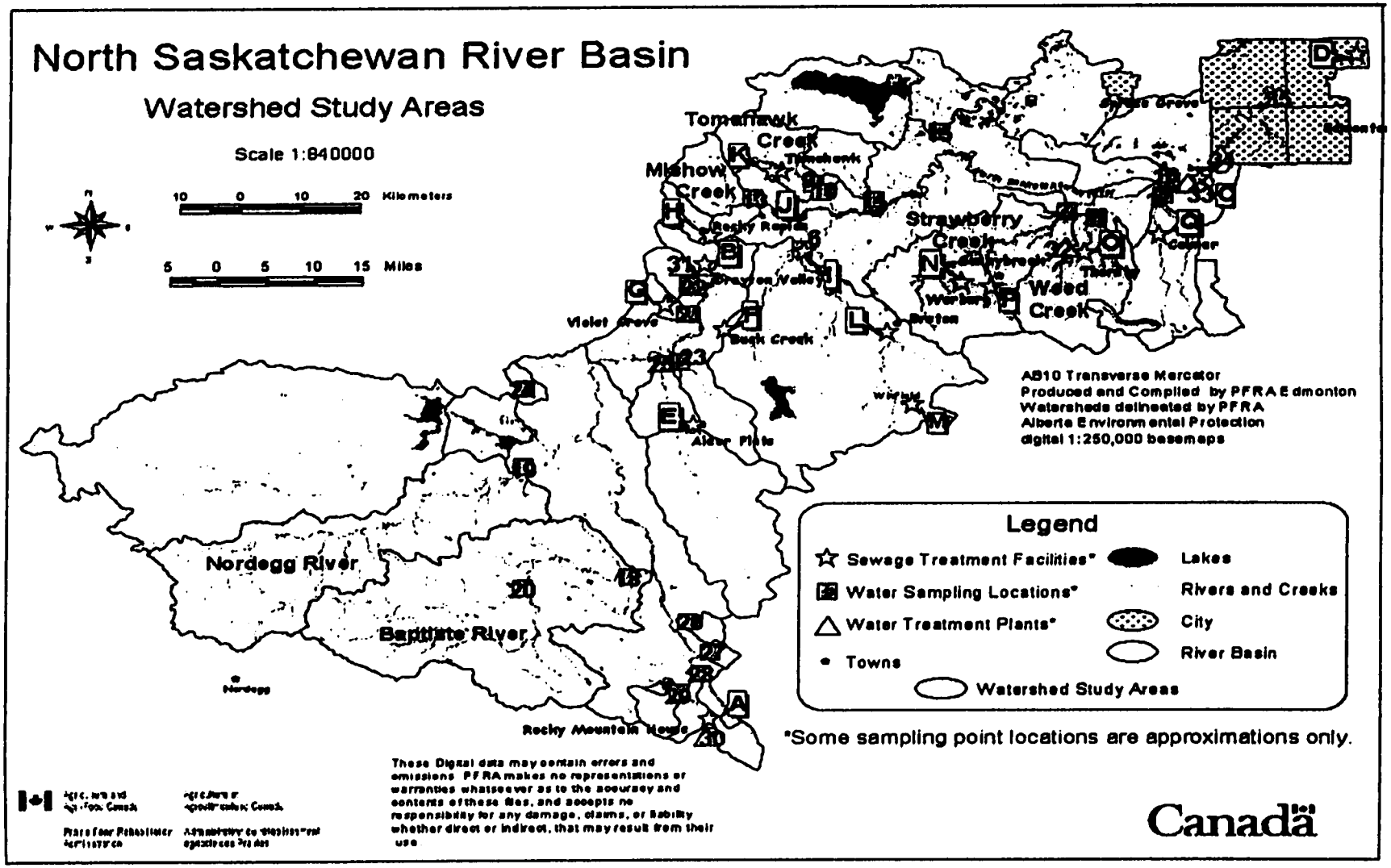

Figure 3.2: Sampling Locations in the North Saskatchewan River Basin Study

concentration data were also available for the two WTPs in the City of Edmonton. The data base extended from December 1992 to December 1999.

3.1.1 River Water Sampling

River water sampling was performed for three distinct studies; the longitudinal survey conducted in 1998 and 1999, and the comparative sub-watershed and the upstream/downstream monitoring studies conducted in 1999. The sampling strategy for each study is described in detail below.

3.1.1.1 Longitudinal Survey

The longitudinal survey was conducted, sampling 19 major tributaries flowing into the NSR, during spring runoff, summer rainstorm events, and fall low flow periods in 1998, and during spring runoff only in 1999. In 1998, spring sampling was conducted from March 22 to April 21, to capture spring runoff data. The summer sampling period was conducted from May 5 to July 7, 1998 to focus on capturing summer rainstorm events. Finally, the fall sampling period was from September 2 to September 17, 1998 to capture low flow events. In 1999, the longitudinal sampling was conducted from April 10 to April 30, to capture spring runoff flow conditions. Each tributary was sampled as close to its mouth as possible, before the tributary merged with the NSR. As well, during spring runoff and rainstorm events, an effort was made to sample as close to the peak flow as possible. The 20 tributaries sampled are summarized in Table 3.2 and the sampling locations are described below, and shown in Figure 3.2.

Prentice Creek Longitudinal Survey Site:

The site is identified on Figure 3.2 as box "29" and it is located 4.0 km north of Highway 11 on the road to Crimson Lake Provincial Park.

Chicken Creek Longitudinal Survey Site:

The site is identified on Figure 3.2 as box "28" and is located 8.5 km north of Highway 11 on Highway 22, 1.6 km west and 0.4 km north on a private road.

Canyon Creek Longitudinal Survey Site:

The site is identified on Figure 3.2 as box "27" and is located 12.6 km north of Highway 11 on Highway 22, and is 15 km North of Rocky Mountain House.

Big Beaver Longitudinal Survey Site:

The sampling location is identified on Figure 3.2 as box "26" and is a culvert crossing located 16 km north of Highway 11 on Highway 22, then 2.75 km down the first westward road. It is south of the Baptiste River.

Baptiste River Longitudinal Survey Site:

The site identified as box "18" on Figure 3.2 was monitored in 1998 for the longitudinal survey. This site is located at the Water Survey of Canada gauging station at the mouth of the Baptiste River.

Nordegg River Longitudinal Survey Site:

The sampling site identified as box "19" in Figure 3.2 and it is located 19 km south of the Brazeau Dam at the bridge crossing of Sunchild Road.

Sand Creek Longitudinal Survey Site:

The site is identified as box "24" in Figure 3.2 and it is located at a culvert crossing 4 km west of Lodgepole on Secondary Highway 620, and 10 km south on Brazeau Power Station Road.

Rose Creek Longitudinal Survey Site:

The site is identified as box "25" in Figure 3.2 and is located 3km west of Alderflats at a Canada/Alberta Environmentally Sustainable Agriculture (CAESA) gauging station.

Washout Creek Longitudinal Survey Site:

The station is identified as box "23" in Figure 3.2 and is located 9.8 km south of Secondary Highway 616 on Highway 22, then 6.0 km west to intersection, 6.0 km north along a winding road, then west at Comstate Resources Road to a washed out bridge, where sampling is performed.

620 Creek Longitudinal Survey Site:

The sampling site is identified as box "22" in Figure 3.2 and is located at a culvert crossing located near the town of Drayton Valley, 0.7 km south of Highway 22 on Secondary Highway 620.

Mishow Creek Longitudinal Survey Site:

The site is identified as box "13" in Figure 3.2 and is located at a bridge crossing site, located on Range Road 64 3 km south of Secondary Highway 624.

Modeste Creek Longitudinal Survey Site:

The sampling site is identified as box "6" in Figure 3.2 and is located near the confluence with the North Saskatchewan River 3 km west of Lindale and 7 km south of the North Saskatchewan River.

Tomahawk Creek Longitudinal Survey Site:

This creek has two sites that were sampled during the longitudinal survey. They are identified as boxes "9" and "10" in Figure 3.2. The site identified as box "9" was originally sampled. However, during high flows it was impossible to sample this site and the site identified as box "10" was used. The sites are very close to one and other, and therefore could easily be taken as the same site during analysis. The site identified as box "9" is located on Highway 624 at Township Road 510 at a CAESA stream gauging station. The site labeled by box "10" is located closer to the mouth at a bridge crossing.

Shoal Lake Creek Longitudinal Survey Site:

The site identified as box "14" in Figure 3.2 as is located at a bridge crossing 1.0 km west of Burtonsville.

Wabamun Creek Longitudinal Survey Site:

The site is identified as box "15" in Figure 3.2 and is located at the Water Survey of Canada flow gauging station upstream of Secondary Highway 627.

Strawberry Creek Longitudinal Survey Site:

The site is identified as box "2" in Figure 3.2 and is located at the Federal stream gauging site near the confluence with the North Saskatchewan River.

Weed Creek Longitudinal Survey Site:

The site is identified as box "1" in Figure 3.2 and is located 11 km west of the town of Calmar on Range Road 281, 3.8 km North of Highway 39 .

Conjuring Creek Longitudinal Survey Site:

The site is identified as box "17" in Figure 3.2 and is located at a culvert crossing on Township Road 514.

Graminia Creek Longitudinal Survey Site:

The original station at Graminia is located at a crossing 2 km north of the Devon Bridge on Highway 60 and 4 km west. A location closer to the mouth was

Table 3.2: Classification of Creeks Based on 1996 Canada Census Beef Cattle Density Data

River Mouth Site Sampled in Longitudinal Study	Descriptor in Figure 3.2	Farm Density* (ha/ha)	Beef Density* (animals/ha)	Livestock Density* (animals/ha)	Classification	Watershed Effective Drainage Area (km^2)
Sand Creek	Box "24"	0.000	0.000	0.000	Wildlife	32.3
Nordegg River	Box "19"	0.076	0.107	0.113	Wildlife	1083.4
Prentice Creek	Box "29"	0.024	0.067	0.065	Wildlife	59.3
Baptiste River	Box "18"	0.124	0.160	0.168	Wildlife	1345.0
Washout Creek	Box "23"	0.730	0.528	0.606	Medium Beef Cattle	136.6
620 Creek	Box "22"	0.569	0.592	0.577	Medium Beef Cattle	57.4
Violet Grove Creek	Box "21"	0.565	0.593	0.578	Medium Beef Cattle	53.8
Rose Creek	Box "25"	0.484	0.608	0.711	Medium Beef Cattle	663.6
Big Beaver Creek	Box "26"	0.469	0.705	0.778	Medium Beef Cattle	29.1
Canyon Creek	Box "27"	0.489	0.708	0.789	Medium Beef Cattle	18.5
Modeste Creek	Box "6"	0.741	0.853	0.913	Medium Beef Cattle	300.6
Shoal Lake Creek	Box "14"	0.707	0.861	0.834	Medium Beef Cattle	122.8
Tomahawk Creek	Box "9" and "10"	0.763	0.956	0.861	High Beef Cattle	97.07
Wabamun Creek	Box "15"	0.693	0.963	0.959	High Beef Cattle	463.9
Mishow Creek	Box "13"	0.816	0.986	0.891	High Beef Cattle	133.7
Chicken Creek	Box "28"	0.846	1.092	1.214	High Agriculture	29.2
Strawberry Creek	Box "2"	0.843	1.177	1.369	High Agriculture	581.5
Weed Creek	Box "1"	1.201	1.932	2.096	High Agriculture	307.5
Conjuring Creek	Box "17"	0.967	1.409	1.791	High Agriculture	261.2
Graminia Creek	Box "16"	0.821	1.390	1.433	High Agriculture	80.7

* Density data was obtained form the 1996 Canada Census

established for sampling in the summer of 1998, and is identified as box "16" in Figure 3.2.

3.1.1.2 Comparative Sub-Watershed Study

The comparative sub-watershed study was undertaken to determine the relative contribution of protozoa from three types of sub-watersheds to determine if agricultural production had a significant effect on protozoan loadings. The sub-watersheds chosen were predominately wildlife, high beef cattle, and high agriculture watersheds. These sub-watersheds were sampled intensively during 1999 at their mouths during spring runoff, summer rainstorm events, and during the fall low flow period.

Data obtained from the 1998 longitudinal survey were analyzed together with 1996 Census of Agriculture/Soil Landscapes of Canada data to choose the study sub-watersheds. The Prairie Farm Rehabilitation Administration clipped the census soil landscape polygons to each sub-watershed and calculated the following: i) beef density as total cattle on pasture land (improved pasture + unimproved pasture) (animals/ha); ii) farm density as the total amount of farm area in the watershed polygon (ha/ha); iii) the livestock density as the total livestock (total cattle + total pigs + total horses + total sheep + total other stock) on the non-cropped area (total farm area – cropland – summer fallow) (animals/ha); and, iv) watershed effective drainage areas (km^2) for each of the sub-watersheds. The 1996 census took place on May 14, 1996 and is, therefore,

representative of spring conditions. The sub-watersheds within the NSR basin watershed were ranked with respect to wildlife (0 to 0.17 animals/ha), medium beef cattle (0.18 to 0.87 animals/ha), high beef cattle (0.88 to 1.0 animals/ha) or high agriculture (1.01 to 1.95 animals/ha) (Table 3.2). Watersheds were chosen first on their beef cattle on pasture density, and then secondly on their effective drainage areas. An attempt was made to choose sub-watersheds with similar densities and effective drainage areas to enable better comparison of the results.

The two wildlife (control) sub-watersheds chosen, in which there was little to no influence from agriculture, industry or municipalities (sewage), were the Baptiste River and the Nordegg River sub-watershed (Figure 3.2). Samples were collected at boxes "18" for the Baptiste River and box "19" for the Nordegg River sub-watersheds. These sub-watersheds would serve as "controls" for comparison with the other sub-watershed loading values. The Baptiste River sub-watershed has an effective drainage area of 1345.0 km^2 and a beef density of 0.160 animals/ha. The Nordegg River sub-watershed has an effective drainage area of 1083.4 km^2 and a beef density of 0.107 animals/ha. Because the Baptiste River sub-watershed has both a higher effective drainage area and beef density ranking, we may expect to see higher protozoan and bacterial loads in this sub-watershed than the Nordegg River sub-watershed.

The two sub-watersheds that had high beef cattle influences but little other agricultural influences were the Mishow Creek and the Tomahawk Creek sub-

watersheds (Figure 3.2). The sampling locations for this study are indicated by box "13" and boxes "9" and "10" for Mishow Creek and Tomahawk Creek sub-watersheds respectively. The Tomahawk sub-watershed has an effective drainage area of 97.07 km^2 and a beef density of 0.956 animals/ha. The Mishow Creek sub-watershed has an effective drainage area of 133.7 km^2 and a beef density of 0.986 animals/ha. Again, because the Mishow Creek sub-watershed has a higher effective drainage area and beef density ranking, we may expect to see higher protozoan and bacterial loads in this sub-watershed than in the Tomahawk Creek sub-watershed.

The two sub-watersheds chosen to represent high agricultural (beef and dairy cattle, hogs) influences were the Strawberry Creek sub-watershed and the Weed Creek sub-watershed (Figure 3.2). The sampling locations for the study are indicated by box "2" and box "1" for Strawberry Creek and Weed Creek sub-watersheds, respectively, in Figure 3.2. The Strawberry Creek sub-watershed has an effective drainage area of 581.5 km^2 and a beef density of 1.177 animals/ha. The Weed Creek sub-watershed has an effective drainage area of 307.5 km^2 and a beef density of 1.932 animals/ha. The effective drainage area of the Strawberry Creek sub-watershed is almost twice as large as that of the Weed Creek sub-watershed. The beef density ranking in the Weed Creek sub-watershed is slightly higher than that of the Strawberry Creek sub-watershed. Due to the larger area of the Strawberry Creek sub-watershed, the loads

observed from this sub-watershed may be substantially higher than the Weed Creek sub-watershed.

3.1.1.3 Upstream/Downstream Monitoring

A study to monitor upstream and downstream of individual beef cattle operations to determine the potential contribution of parasites to surface waters from such operations was performed in 1999. The upstream/downstream monitoring allows for comparison of water quality attributes and parasite concentrations before water flows through contributing areas, and after if flows through those areas. The apparent difference in contributions will be determined by identifying the relative differences between upstream and downstream concentrations.

The criteria for selecting the sub-watersheds in which the upstream/downstream study would occur were based on seven factors:

1. Willingness of cooperators for stream sampling and fecal collection from herd.
2. Proximity of operation(s) to stream. Topography, and/or setting promotes runoff and drainage from farm to stream.
3. Sampling sites located upstream and downstream are feasible for monitoring and accessible.
4. Other influences that could contribute parasites to surface waters are minimal (i.e., there is not the influence of other agricultural operations like hog or dairy that could be potential sources of parasites).
5. Herd(s) may be positive for *Cryptosporidium* spp. and/or *Giardia* spp.

6. Water quality data from longitudinal survey of the NSR basin watershed suggest high *Cryptosporidium* spp. and/or *Giardia* spp. concentrations in the watershed.
7. Selected watersheds will have a minimum of other factors that may contribute parasites to water (cattle vs livestock [hog, dairy, etc.] densities in the watershed have been minimized).

Upstream/downstream monitoring of participating beef cattle operations was performed in the Weed Creek sub-watershed. The sampling sites upstream were identified as sites 3 and 4, and the downstream site was site 5. Upstream/downstream monitoring of a beef cattle operation was also performed in the Tomahawk Creek sub-watershed, with the upstream site being number 7 and the downstream site number 8. As well, upstream/downstream monitoring was performed in the Mishow Creek sub-watershed, with the upstream site being number 12 and the downstream site number 13. The sampling locations of the upstream/downstream sites in Weed Creek, Tomahawk Creek and Mishow creek are not shown in Figure 3.2 to protect the anonymity of the participating cooperators.

3.1.2 Wastewater Treatment Plant Effluent Sampling

There are four mechanical, continuously discharging WWTP in the NSR basin upstream of, and including, the City of Edmonton that were sampled in 1998 and 1999. These WWTPs were located in the towns of Rocky Mountain House,

Drayton Valley, Devon and the City of Edmonton (the Gold Bar WWTP). The WWTPs are identified in Figure 3.2, above, as follows; Rocky Mountain House WWTP is star "A", Drayton Valley WWTP is star "B", Devon WWTP is star "C", and Gold Bar WWTP is star "D".

The WWTPs are summarized in Table 3.3, below, and a detailed description and plan of each WWTP can be found in Appendix B. The Rocky Mountain House WWTP is the only one that does not practice chemical microorganism reduction its wastewater prior to discharging the effluent.

3.1.3 Sewage Treatment Lagoon Effluent Sampling

Periodic discharge of STL effluent was sampled from 11 of 13 STL in the NSR basin upstream of the City of Edmonton during their discharge periods. Each STL is shown in Figure 3.2, as stars "E" to "Q", and a more detailed description and layout of each lagoon can be found in Appendix C.

Table 3.4, below, summarizes the characteristics of the lagoons. As well, it indicates which letter in Figure 3.2 represents which lagoon. The Birchwood Village STL did not discharge either year during the study. The Buck Creek STL discharged in 1999, however, the effluent was not sampled. All STL except the Tomahawk (main) STL and the Buck Creek STL are permitted to discharge once per year for a maximum length of three weeks from April 1 to November 30. The Tomahawk (main) STL is permitted to discharge twice each year for a maximum length of three weeks each time from March 1 to November 30. The Buck Creek

STL is permitted to discharge twice each year for a maximum length of three weeks each time from April 1 to November 30. A history of the thirteen STL discharges from 1995 to 1999 is shown in Appendix C.

3.1.4 Drinking Water Treatment Plant Sampling

There were six WTPs sampled within the NSR basin upstream of, and including, the City of Edmonton. The six WTPs are located in the towns and villages of Rocky Mountain House, Drayton Valley, Thorsby, Devon and two within the City of Edmonton (the E.L. Smith and Rossdale WTPs). The location of the WTPs are shown as triangles "30" to "35" in Figure 3.2.

The WTPs are summarized in Table 3.5, and a more detailed description and plan of each water treatment plant can be found in Appendix D. The Thorsby WTP is not located directly on the NSR, however it obtains its water from the NSR transported through an ESSO water withdrawal pipeline. Thorsby pumps the NSR water to a large holding tank, and usually only pumps water when the NSR has low turbidity. All other plants are located directly on the banks of the NSR. The Thorsby WTP is the smallest, serving a population of 750 people and having a design capacity of 0.91 ML/day. The Rocky Mountain House, Drayton Valley and Devon WTP are all roughly the same size serving populations of

Table 3.3: Characteristics of the Continuous Discharge Wastewater Treatment Plants in the North Saskatchewan River Basin Upstream of, and Including the City of Edmonton

Wastewater Treatment Plants	Descriptor in Figure 3.2	Disinfection Method Prior to Effluent Discharge	Wastewater Received	Design Capacity (ML/day)	Population Served	Creek/River Effluent Discharged Into[+]
Rocky Mountain House	Star "A"	None	<1% meat packing plant 5% car washes 94% human waste	3.75	6 062	Trapper Creek
Drayton Valley	Star "B"	Chlorination	100% human waste (does not receive agricultural/ industrial waste	15[@]	7 000	North Creek
Devon	Star "C"	Chlorination	99 % municipal waste (does not accept agricultural/ industrial waste)	3.9	5 000	North Saskatchewan River
Goldbar*	Star "D"	Chlorination and UV radiation	Human waste and storm water, industrial wastewater	310 (2° and 3°), 920 (1°)	650 000	North Saskatchewan River

* Goldbar Wastewater Treatment Plant is located in the City of Edmonton
[+] All Creeks flow directly into the North Saskatchewan River
[@] Design Capacity of extended aeration cells only in ML
1° = primary treatment, 2° = secondary treatment, 3° = tertiary treatment

Table 3.4: Characteristics of the Sewage Lagoon Facilities in the North Saskatchewan River Basin Upstream of Edmonton

Sewage Lagoons	Descriptor in Figure 3.2	Creek Effluent Discharged Into*	Population Lagoon Serves	Storage Cell Capacity (m^3)	Wastewater Type Receives	Transportation Method of Wastewater to Lagoon	Lagoon Sludge Management
Alderflats	Star "E"	Rose Creek	140	26 800	100% human waste	90% piped in, 10% trucked in	None
Birchwood Village	Star "I"	Modeste Creek	70	19 120	99% human waste, 1% industrial waste	Trucked to lagoon	None
Breton	Star "L"	Modeste Creek	521	90 900	100% human waste	Trucked and piped to lagoon	None
Buck Creek	Star "F"	Unnamed Creek	100	24 313	99% human waste, 1% industrial waste	Piped to lagoon	None
Calmar	Star "Q"	Conjuring Creek	1 800	239 425	100% human waste	Piped to lagoon	Field application
Rocky Rapids	Star "H"	Unnamed Creek	130	54 000	99% human waste, 1% industrial waste	Piped to lagoon	Land Application

continued on next page

Sewage Lagoons	Descriptor in Figure 3.2	Creek Effluent Discharged Into[+]	Population Lagoon Serves	Storage Cell Capacity (m^3)	Wastewater Type Receives	Transportation Method of Wastewater to Lagoon	Lagoon Sludge Management
Sunnybrook	Star "P"	Strawberry Creek	70	15 470	100% human waste	Piped to lagoon	None
Thorsby	Star "O"	Weed Creek	725	195 000	100% human waste	Piped to lagoon	None
Tomahawk (main)	Star "J"	Tomahawk Creek	130	9 565 *	100% human waste	Piped to lagoon	None
Tomahawk (school)	Star "K"	Tomahawk Creek	100 [+]	6 371[@]	100 % human waste	Piped to lagoon	None
Violet Grove	Star "G"	Unnamed Creek	80	25 000	99% human waste, 1% industrial waste	Piped to lagoon	None
Warburg	Star "N"	Strawberry Creek	549	118 608	Animal and human	Piped to lagoon	None
Winfield	Star "M"	Modeste Creek	240	11 250	100% human waste	Piped to lagoon	None

[+] All Creeks flow directly into the North Saskatchewan River

[♦] Combined volume of facultative and storage cell

* Calculations based on assumed depth of sludge (1.5 m)

[@] Lagoon operates only during school hours

Table 3.5: Characteristics of the Water Treatment Plants in the North Saskatchewan River Basin Upstream of, and Including, the City of Edmonton

Water Treatment Plants	Descriptor in Figure 3.2	Treatment Process at Plant	Population Served	Design Capacity (ML/day)
Rocky Mountain House	Triangle "30"	Solids contact clarifier, Chemical coagulation, Sand filtration and Chlorination (gas)	6 062	8.4
Drayton Valley	Triangle "31"	2 day retention settling pond, screens, Upflow clarifiers, liquid alum and polymer, Dual media (anthracite + sand) gravity filter, Chlorination (gas) and fluoridation	6 000	6.5
Thorsby	Triangle "32"	Flocculation, coagulation, sedimentation, slow sand filtration, chlorination, fluoridation	750	0.91
Devon	Triangle "33"	1 solids contact reactor (scr) clarifier, 4 rapid sand filters, post chlorination and fluoridation, (a 2nd scr clarifier is under construction)	5 000	7.2
E.L. Smith*	Triangle "34"	3 upflow clarifiers with tube settlers, enhanced alum coagulation with an anionic polymer coagulation aid, Lime softening and recarbonation, free chlorine, ammonia and fluoridation, dual media filtration (anthracite + sand), PAC used for taste and odour	434 000+	190
Rossdale*	Triangle "35"	Cross flow clairfiers with tube settlers, Tapered flocculation and sedimentation, Enhanced alum coagulation with an anionic polymer coagulation aid, Lime softening and recarbonation, free chlorine, ammonia and fluoridation, PAC used for taste and odour	381 000+	214

* E.L. Smith and Rossdale WTP are located in the City of Edmonton

+ Population served by these plants is estimated by percent of water supplied by each plant and is only approximate. The values changes from month to month and may vary substantially when one plant is down for maintenance

6 062, 6 000, and 5 000 people, respectively, and having design capacities of 8.4, 6.5, and 7.2 ML/day, respectively. The EL Smith and Rossdale WTPs are significantly larger, serving a combined population of 815 000 people.

3.2 Laboratory Analysis

Water chemistry samples were analyzed at the Alberta Research Council Laboratory in Vegreville (1998) and EnviroTest Laboratories in Edmonton (1999). Fecal coliform bacteria, *Escherichia coli* and *Camplyobacter* spp. samples were analyzed at the Provincial Laboratory of Public Health in Edmonton both years. For protozoans, source and treated water were analyzed according to the ICR method (USEPA 1995) with immunofluorescent assay for (oo)cyst identification. Effluent samples were concentrated with a continuous-flow centrifugation system (Goatcher 1995).

3.2.1 Preparation of Water Sample Controls

The water sample negative control was prepared and processed according to the ICR procedure. The control is used as a check on equipment, materials, reagents and technique. The negative controls were processed for each batch of filters processed in the course of one week. At no time were there any cysts or oocysts detected while processing a negative control sample, and therefore no samples in any batches had to be excluded from the ICR database.

In 1998, the EPCOR Water Services Laboratory obtained USEPA vial "B" samples to perform positive controls testing and calculate percent recoveries. The average percent recovery for 1998 was 20.7% and 41.0% for *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts, respectively (based on 36 sample runs for each protozoan). In 1999, the EPCOR Water Services Laboratory was unable to locate USEPA vial "B" positive control samples, and therefore had difficulty performing positive control samples. However, they were able to obtain *Cryptosporidium* spp. samples from the University of Florida. For 1999, their average percent recovery for *Cryptosporidium* spp. oocysts was 19.6% (based on 12 positive control runs).

3.2.2 Method Detection Limit

The method detection limit for protozoan analysis is dependent on the quality of the source water analyzed. The EPCOR Water Services Laboratory targets a detection limit of < 100 (oo)cysts per 100 L for all environmental samples. They determine their detection limit for treated drinking water as approximately 1 (oo)cyst per 1000 L while the detection limit is higher in river and effluent samples.

3.3 Quality Assurance and Quality Control

Throughout the sampling during 1998 and 1999, quality assurance splits were taken in the field for both the protozoan samples and chemical samples analyzed by the laboratories. Splits were taken in duplicate and triplicate, and quality

assurance was maintained by sending these splits as blinds to the laboratories. The protozoan and turbidity samples were sent as blinds to EPCOR Water Services for analysis. As well a quality assurance/quality control program was undertaken, sending the water chemical samples to three different laboratories.

4 RESULTS AND DISCUSSION

In this section the historical flows for the North Saskatchewan River will be summarized to put into perspective the type of flow years that were observed during the study period. As well, flow data from six of the tributaries flowing into the North Saskatchewan River are also summarized. An overview of the concentration data obtained from the longitudinal survey, the effluent sampling at the WWTP and STLs, raw and finished drinking water from the WTPs, the comparative watershed analysis, and the upstream/downstream study are all presented and summarized. Finally, the long term historical concentrations observed at the two WTPs in the City of Edmonton are summarized. The 1999 concentration data from the EL Smith WTP is converted to loadings as loads per day. The concentration data from the WWTP, STL and the comparative watershed study are also converted to loads per day, and a rough estimate of their contribution to the loads observed at the EL Smith plant throughout 1999 is presented.

4.1 Methods of Data Analysis

For fecal coliform and *Escherichia coli* data, ½ the detection limit was used for all censored data (data below method detection limit) in calculations. All *Cryptosporidium* spp. and *Giardia* spp. censored data in the raw data set was replaced with the full detection limit for calculation purposes. This decision was made based on LeChevallier and Norton (1995) who state that for the

determination of risk to a water utility the full detection limit or the 90th percentile should be used in calculations. Therefore, to properly determine the highest risk to the water utilities in the NSR basin, the full detection limit was used for censored data in all calculations. It is acknowledged that there may be the risk of including false positives when this method is employed however, due to the low percent recoveries of the ICR (1995 method) there runs a greater risk of not assuming a high enough risk if only ½ the detection limit is used in calculations, or even worse, if censored data is eliminated from the working data set.

Table 4.1 summarizes the percentage of *Cryptosporidium* spp. and *Giardia* spp. concentration data that was below detection limit for all sampling. It was found that 15.8% of the longitudinal survey data for 1998 and 1999, 21.8% of the WWTP data for 1998 and 1999, 25.0% of STL data for 1998 and 1999, 26.8% of the comparative watershed study data for 1999, 47.5% of the raw water samples at the WTPs upstream of Edmonton for 1999, and 97.4% of the finished water samples at the WTPs upstream of Edmonton for 1999 were below the detection limit. The historical *Cryptosporidium* spp. and *Giardia* spp. concentrations at EL Smith WTP and Rossdale WTP from December 14, 1992 to December 20, 1999 were analyzed, and it was found that 29.8% and 24.1% of the samples were below detection limit for the EL Smith and Rossdale WTPs respectively.

Data used in the loading calculations included the WWTP effluent samples, STL effluent samples, Comparative sub-watershed study samples and the EL Smith

WTP source water samples. Since the percentages of data below detection limit are relatively small for data used in the loading calculations (21.8 to 29.8 %), substituting the full detection limit will not yield results substantially higher than those that would have been attained by using the 90th percentile or ½ detection

Table 4.1: Percentage of Samples Below Detection Limit for Protozoa Sampling

Sampling Location	Percentage of Samples Below Detection Limit	Number of Samples Below Detection Limit/ Total Number of Samples
Longitudinal Survey Samples, 1998 and 1999	15.8	24/152
WWTPs in NSR Basin, Effluent Samples, 1998 and 1999	21.8	17/78
STLs in NSR Basin, Effluent Samples, 1998 and 1999	25.0	8/32
Comparative Watershed Study and Upstream/Downstream Study Samples, 1999	26.8	91/340
WTPs Upstream of Edmonton in NSR Basin Source Water Samples, 1999	47.5	19/40
WTPs Upstream of Edmonton in NSR Basin Finished Water Samples, 1999	97.4	37/38
EL Smith WTP Source Water Samples, 1992-1999	29.8	53/178
Rossdale WTP Source Water Samples, 1992-1999	24.1	54/224

limit values for censored data. The finished water samples for WTPs upstream of the City of Edmonton contained 97.4% that were below detection limit. It is expected that the finished water samples at WTPs will have a high percentage of data below detection limit.

4.2 Historical Flow Data Analysis

The discharge data (m^3/s) from Environment Canada (Water Survey of Canada) was obtained for the North Saskatchewan River at Edmonton (1911-1999), Strawberry Creek (1966-1999), Tomahawk Creek (1984-1999), Rose Creek (1972-1999), and Modeste Creek (1996-1999). The long term period of 1984-1999 (16 year trend) was analyzed for each river or creek that had historical data for that length. Modeste Creek was the only creek that did not have long term data.

The discharge data (m^3/s) obtained were converted to total daily flows (m^3/day) and then summed for the year. These total annual volumes ($m^3/year$) were ranked and plotted (Figures 4.1 to 4.7). The total annual volume of flow (m^3) for each year was then divided by the watershed area (m^2) to obtain the total unit runoff (mm). These data and graphs are also shown in Appendix E.

4.2.1 North Saskatchewan River

Flows in the NSR at Edmonton for the study years, 1998 and 1999, both ranked in the 25th percentile (Figure 4.1). 1998 and 1999 were the lowest and second

lowest flow periods respectively in the 16 year historical analysis. The years 1988 and 1989 also rank in the 25th percentile, and the two years prior to the study years, 1996 and 1997, ranked in the 50th percentile when compared with the 16 years of historical flow data. The highest flow recorded in the 16 year analysis period was in 1986.

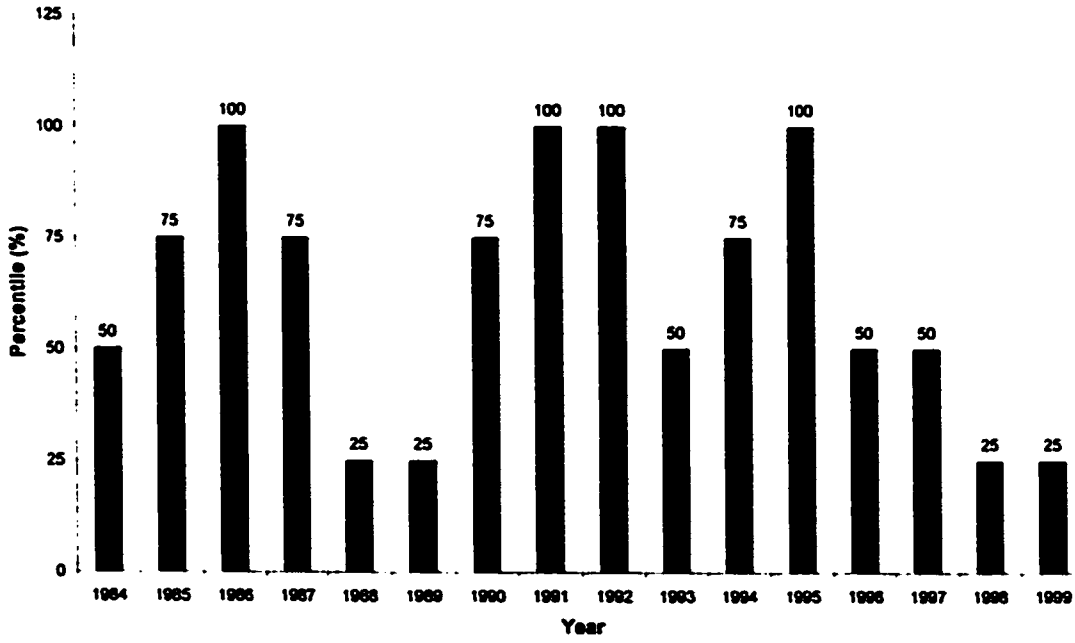

Figure 4.1: Percentile Distribution of Total Annual Volume (m^3) of the North Saskatchewan River at Edmonton for the Years 1984 to 1999

4.2.2 Strawberry Creek

Strawberry Creek is a typical high agriculture sub-watershed in the NSR basin as described in Table 3.2. Flows in Strawberry Creek for 1998 were the second lowest observed over the 16 year historical flow analysis period. In 1999, the flows were significantly higher and fell in the 75th percentile ranking (Figure 4.2).

The years 1988 and 1989 ranked in the 50th and 75th percentiles respectively. The two years prior to the study years, 1996 and 1997, ranked in the 75th and 100th percentiles respectively when compared with the 16 years of historical flow data. The lowest flow year was recorded in 1995, and the highest in 1990 over the 16 year analysis period.

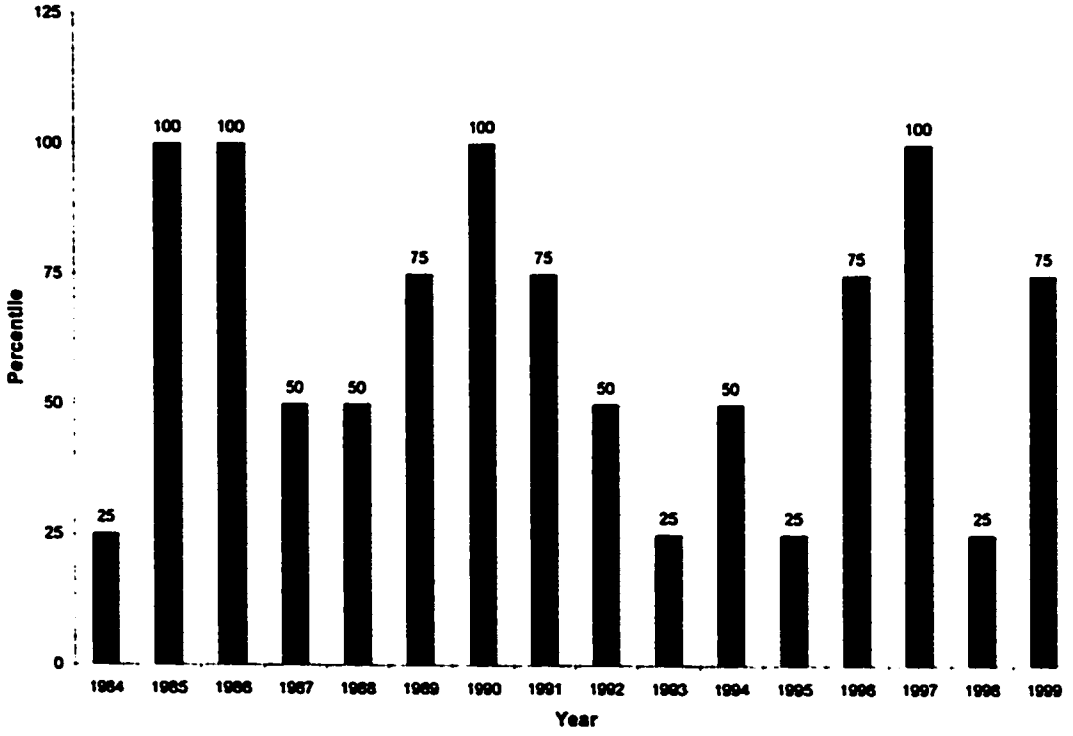

Figure 4.2 Percentile Distribution of Total Annual Volume (m^3) of Strawberry Creek for the Years 1984 to 1999

4.2.3 Tomahawk Creek

Tomahawk Creek is a typical high beef cattle sub-watershed in the NSR basin as described in Table 3.2. Flows in Tomahawk Creek for 1998 were the lowest observed over the 16 year historical flow analysis period. In 1999, the flows were higher, falling into the 50th percentile ranking (Figure 4.3). The years 1988 and 1989 ranked in the 50th and 100th percentiles respectively, with 1989 being the

highest flow year recorded. The two years prior to the study years, 1996 and 1997, both ranked in the 100th percentile when compared with the 16 years of historical flow data.

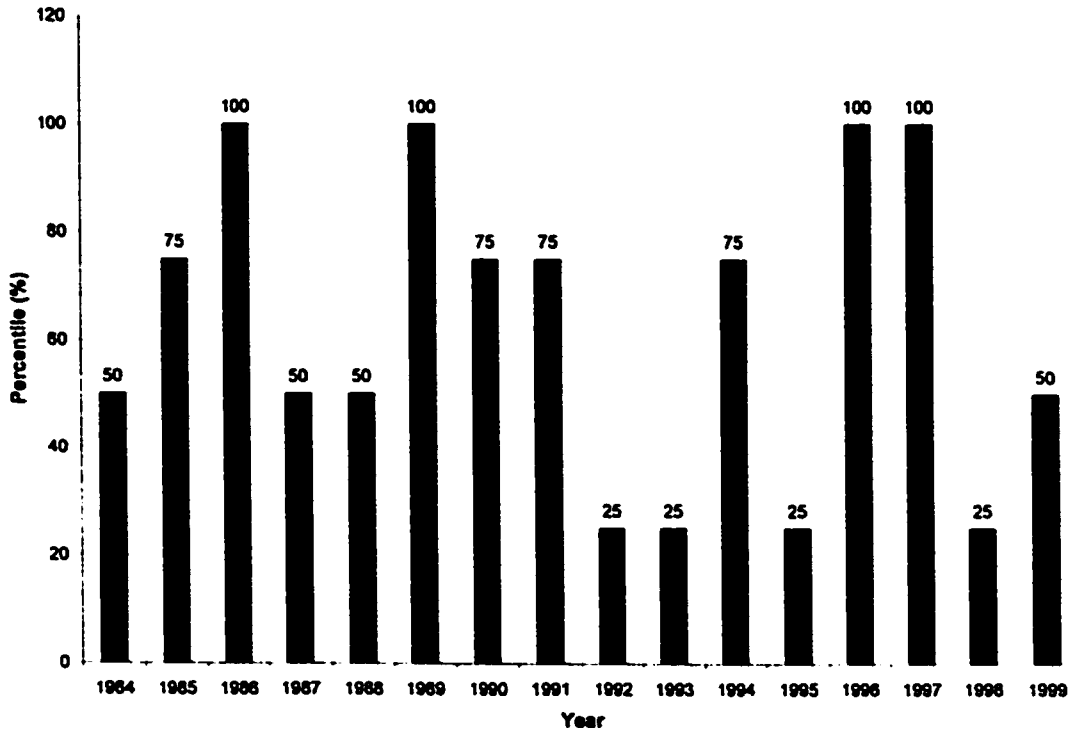

Figure 4.3 Percentile Distribution of Total Annual Volume (m^3) of Tomahawk Creek for the Years 1984 to 1999

4.2.4 Baptiste River

The Baptiste River is a typical wildlife sub-watershed in the NSR basin as described in Table 3.2. Flows in the Baptiste River for 1998 were in the 75th percentile ranking, as were the flows in 1996 and 1997. For 1999 the flows in the Baptiste River fell into the 100th percentile ranking as indicated in Figure 4.4. The years 1988 and 1989 ranked in the 25th and 100th percentiles respectively.

The Baptiste River shows three year flow repetitious patterns. The lowest flow period was observed in 1984, and the highest in 1990 over the 16 year analysis period.

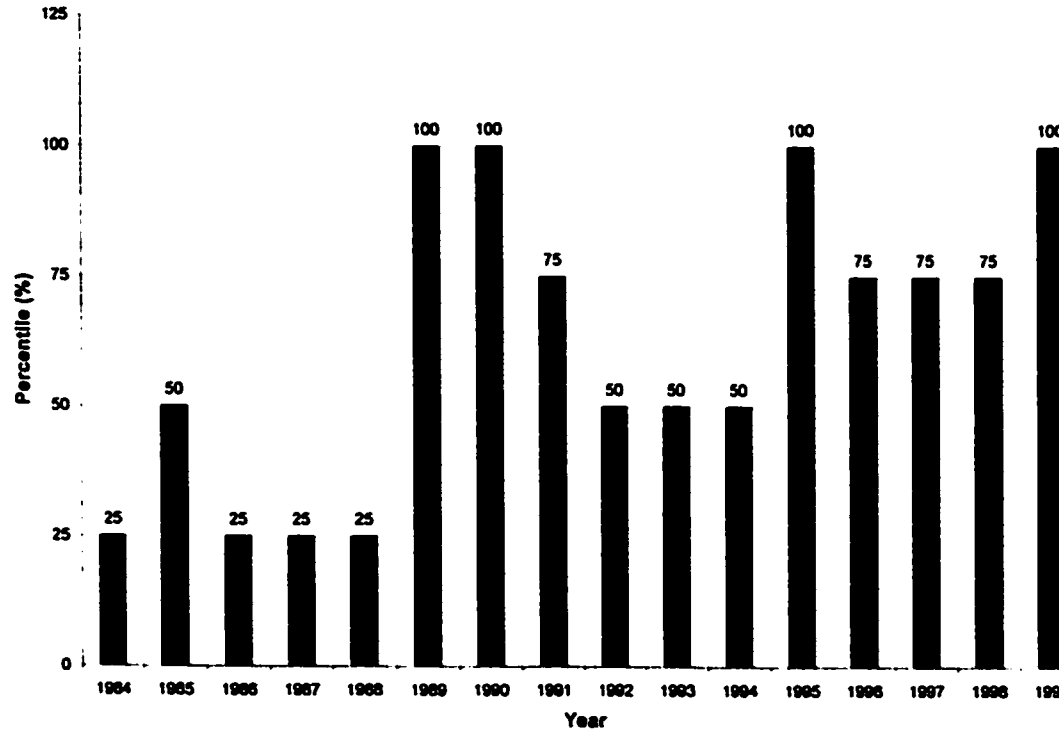

Figure 4.4 Percentile Distribution of Total Annual Volume (m^3) of the Baptiste River for the Years 1984 to 1999

4.2.5 Nordegg River

Nordegg River is another typical wildlife sub-watershed in the NSR basin as described in Table 3.2. Flows in the Nordegg River for 1998 and 1999 were similar to those in the Baptiste River, the other wildlife sub-watershed, being in the 75th and 100th percentile respectively for the historical flow analysis period.

Figure 4.5, below. The flows in the year 1988 were the lowest recorded for the flow analysis period. In 1989 the flows ranked in the 75th percentile. The two years prior to the study years, 1996 and 1997, both ranked in the 50th percentile when compared with the 16 years of historical flow data. The highest flow year over the 16 year analysis period at the Nordegg River was observed in 1986.

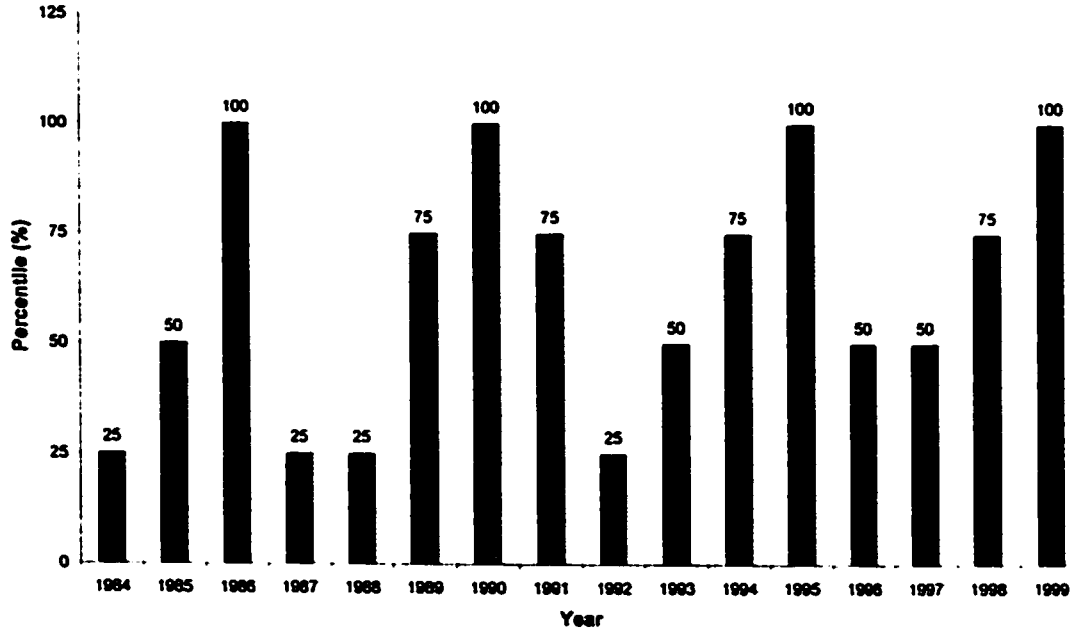

Figure 4.5 Percentile Distribution of Total Annual Volume (m^3) of the Nordegg River in the Years 1984 to 1999.

4.2.6 Rose Creek

Rose Creek is a typical medium beef cattle sub-watershed as described in Table 3.2. Flows in Rose Creek for 1998 and 1999 were in the 75th and 100th percentile respectively for the historical flow analysis period (Figure 4.6). The flows in the year 1988 were the second lowest recorded for the flow analysis

period. In 1989 the flows ranked in the 75th percentile. The two years prior to the study years, 1996 and 1997, ranked in the 100th and 75th percentile respectively when compared with the 16 years of historical flow data. The highest flow period in the analysis period was in 1986, and the lowest was in 1984.

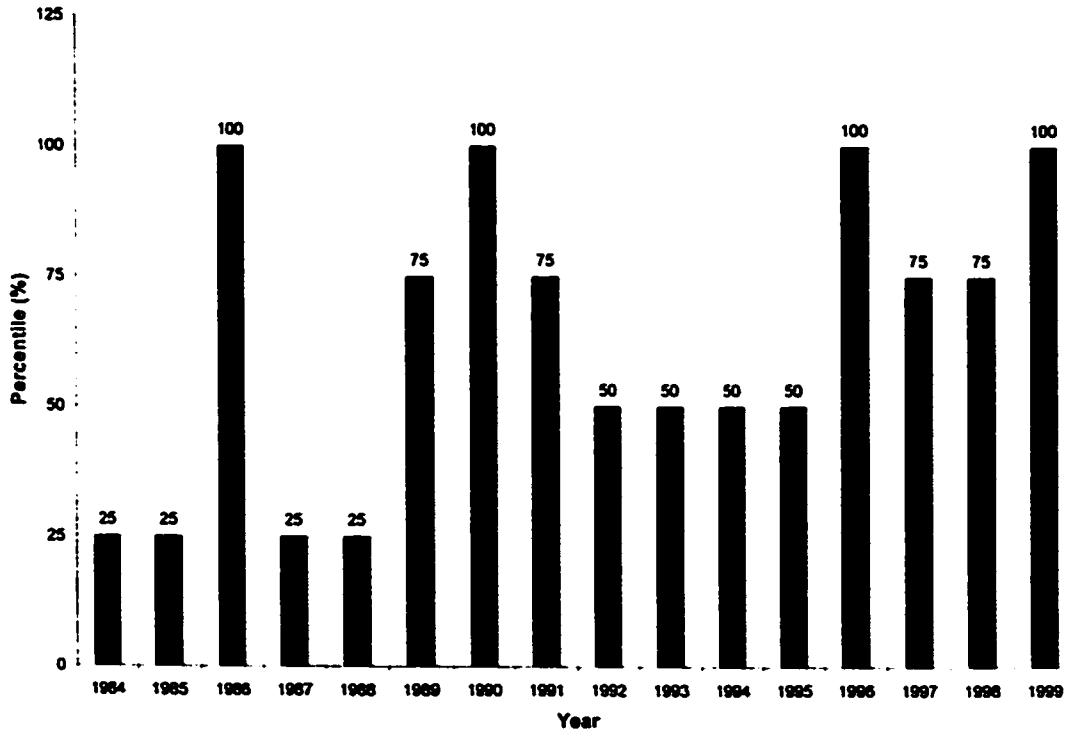

Figure 4.6 Percentile Distribution of Total Annual Volume (m^3) for Rose Creek from 1984 to 1999.

4.2.7 Modeste Creek

Modeste Creek is a typical medium beef cattle sub-watershed as described in Table 3.2. Historical flows have only been available for Modeste Creek since 1996. At the time this report was written, the 1999 flow data had not been made available yet. Therefore, the three-year historical data is summarized below.

The highest flow period was observed in 1996 and the lowest in 1998. With this limited data, it is difficult to say with certainty that 1996 was a typical high flow period and that 1998 was a typical low flow period for Modeste Creek.

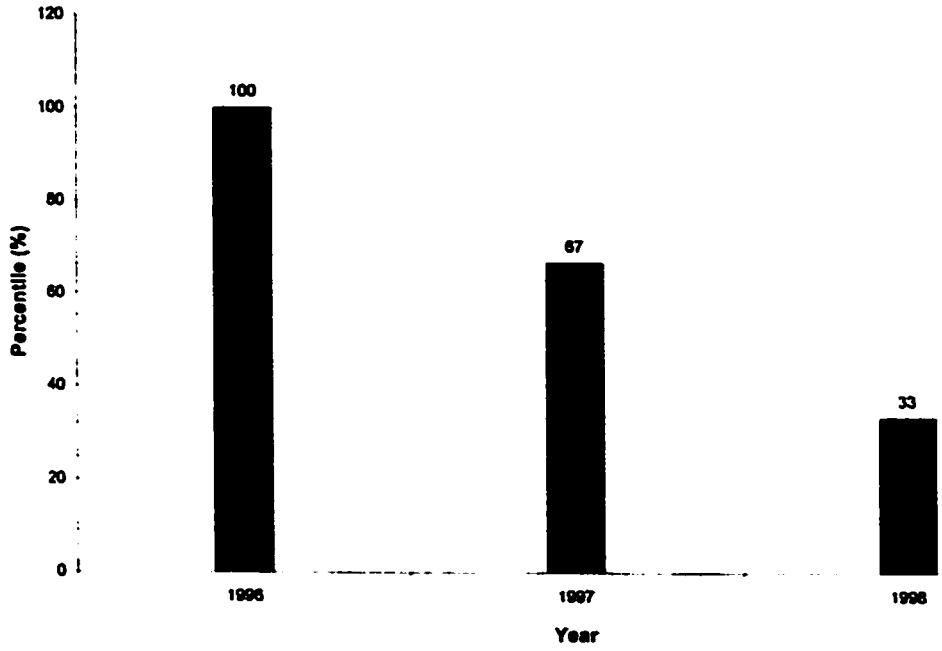

Figure 4.7 Percentile Distribution of Total Annual Volume (m3) for Modeste Creek for the Years 1996 to 1998.

4.3 Longitudinal Survey Data Analysis

In 1998 the longitudinal survey was conducted during spring runoff, summer rainstorm events and during the fall low-flow for streams that still were flowing. The creeks have been categorized as wildlife, high beef cattle and high agriculture as described in the methodology section. The protozoan and

microbiological data were log-normally distributed, and therefore the geometric means of protozoan and microbiological data were calculated. The turbidity data were normally distributed, and therefore the arithmetic means were calculated. These data are shown in Tables 4.2 to 4.4. The 1998 longitudinal survey concentration data summarized in Tables 4.2 to 4.4 are shown Appendix F.

The longitudinal survey was continued during spring runoff in 1999 and the geometric means of the protozoan and microbiological data as well as the arithmetic mean of the turbidity data are presented in Table 4.5. The 1999 longitudinal survey concentration data summarized in Table 4.5 are shown in Appendix F. It is intended that the longitudinal survey will serve as background information and will be an indication of the protozoan concentrations presently in the watershed. As well, this information will serve as historical flow information, which is generally difficult to obtain.

During the spring runoff sampling period in 1998 (March 22 to April 21) a total of 99 samples were taken and are summarized in Table 4.2. A total of 117 samples were taken during the spring runoff sampling period in 1999 (April 10 to April 30), Table 4.5. The geometric mean and arithmetic mean of all the high agriculture cattle sub-watershed results were higher in 1999 than in 1998. For the high beef cattle watersheds, the geometric and arithmetic means were higher in 1999 for all values except for *Cryptosporidium* spp. The geometric mean of *Cryptosporidium* spp. in high beef cattle sub-watersheds was substantially higher

in 1998 than in 1999. For the wildlife sub-watersheds, all values were higher in 1999 than 1998 except for turbidity, which was slightly higher in 1998. In 1998 all samples during spring runoff were below the 150 nephalometric turbidity unit (NTU) limit recommended by the ICR sampling protocol. In 1999, however, the arithmetic mean of turbidity samples in the high beef cattle and high agriculture sub-watersheds was 231 and 487 NTU, respectively.

During the summer rainstorm events of 1998 (May 5 to July 7), a total of 115 longitudinal survey samples were collected (Table 4.3). All the geometric and arithmetic mean values for the wildlife sub-watersheds were higher during the summer rainstorm events than during spring runoff in 1998. For both the high beef cattle and high agriculture sub-watersheds, all geometric and arithmetic mean values except for *Cryptosporidium* spp. were higher during the summer rainstorm events than during spring runoff of 1998. The geometric mean of the *Cryptosporidium* spp. concentration data was higher for both during spring runoff in 1998. It is of interest to note that the arithmetic mean of all turbidity data during the summer rainstorm events were above the 150 NTU limit recommended by the ICR. All arithmetic means of turbidity data were well below the 150 NTU limit during 1998 spring runoff.

A total of 30 samples were collected during fall low-flow periods in 1998 (September 2 to September 17) (Table 4.4). All geometric mean and arithmetic mean data for low flow periods in 1998 were below 1998 spring runoff values,

Table 4.2: Geometric Mean and Ranges of *Cryptosporidium* spp., *Giardia* spp., Fecal coliform, and *E. coli* and Arithmetic Mean of Turbidity for the Spring* Longitudinal Survey of the North Saskatchewan River Basin, Upstream of the City of Edmonton, 1998.

Variable	Wildlife Watersheds	High Beef Cattle Watersheds	High Agriculture Watersheds
Cryptosporidium spp., oocysts/100 L Geometric Mean Range N	54 5 to 230 4	6 654 470 to 99 000 9	2 349 280 to 16 000 8
Giardia spp., cysts/100 L Geometric Mean Range n	152 21 to 690 4	36 <14 to 740 9	473 <85 to 1 100 8
Fecal Coliform, cfu/100 mL Geometric Mean Range n	5 <10 to <10 4	15 <10 to 100 10	16 <10 to 57 8
Escherichia coli, cfu/100 mL Geometric Mean Range n	5 <10 to <10 4	17 <10 to 100 10	15 <10 to 57 8
Turbidity, NTU Mean Range n	11 2.31 to 16.3 4	33 5 to 90.8 4	30 12 to 54.2 5

*Data collected March 22 to April 21, 1998. Beef density estimates (animals/ha) within watersheds: wildlife 0 to 0.17, medium beef cattle 0.18 to 0.87, high beef cattle 0.88 to 1.0, high agriculture 1.01 to 1.95
NTU = nephalometric turbidity unit

Table 4.3 Geometric Mean and Ranges of *Cryptosporidium* spp., *Giardia* spp., Fecal coliform, and *E. coli* and Arithmetic Mean of Turbidity for the Summer* Longitudinal Survey of the North Saskatchewan River Basin, Upstream of the City of Edmonton, 1998

Variable	Wildlife Watersheds	High Beef Cattle Watersheds	High Agriculture Watersheds
Cryptosporidium spp., oocysts/100 L Geometric Mean Range n	1 081 21 to 25 000 5	1 843 400 to 6 400 10	1 062 88 to 7 500 8
Giardia spp., cysts/100 L Geometric Mean Range n	814 10 to <8 300 5	230 53 to 2 700 10	858 88 to 4 800 8
Fecal Coliform, cfu/100 mL Geometric Mean Range n	49 <10 to 120 5	1 127 60 to 63 000 9	738 220 to 5 900 9
Escherichia coli, cfu/100 mL Geometric Mean Range n	40 <10 to 100 5	850 30 to 47 000 9	655 170 to 5 900 9
Turbidity, NTU Mean Range n	362 2.7 to 1080 5	202 4.34 to 789 10	194 11 to 365 8

* Data collected from May 5 to July 7, 1998. Beef density estimates (animals/ha) within watersheds: wildlife 0 to 0.17, medium beef cattle 0.18 to 0.87, high beef cattle 0.88 to 1.0, high agriculture 1.01 to 1.95
NTU = nephalometric turbidity unit

Table 4.4 Geometric Mean and Ranges of *Cryptosporidium* spp., *Giardia* spp., Fecal coliform, and *E. coli* and Arithmetic Mean of Turbidity for the Fall* Longitudinal Survey of the North Saskatchewan River Basin, Upstream of the City of Edmonton, 1998

Variable	Wildlife Watersheds	High Beef Cattle Watersheds	High Agriculture Watersheds
Cryptosporidium spp., oocysts/100 L Geometric Mean Range N	22 8 to 18 3	18 180 to 220 3	434 400 to 450 4
Giardia spp., cysts/100 L Geometric Mean Range N	192 180 to 220 3	78 12 to 480 3	248 61 to 1 400 4
Fecal Coliform, cfu/100 mL Geometric Mean Range N	No data	No data	No data
Escherichia coli, cfu/100 mL Geometric Mean Range N	No data	No data	No data
Turbidity, NTU Mean Range N	1 0.9 to 1.6 3	8 5.6 to 10.3 3	13 3 to 42 4

* Data collected from September 2 to September 17, 1998. Beef density estimates (animals/ha) within watersheds: wildlife 0 to 0.17, medium beef cattle 0.18 to 0.87, high beef cattle 0.88 to 1.0, high agriculture 1.01 to 1.95
NTU = nephalometric turbidity unit

Table 4.5 Geometric Mean and Ranges of *Cryptosporidium* spp., *Giardia* spp., Fecal coliform, and *E. coli* and Arithmetic Mean of Turbidity for the Spring* Longitudinal Survey of the North Saskatchewan River Basin, Upstream of the City of Edmonton, 1999

Variable	Wildlife Watersheds	High Beef Cattle Watersheds	High Agriculture Watersheds
Cryptosporidium spp., oocysts/100 L Geometric Mean Range n	 145 50 to 260 5	 586 25 to 22 000 9	 4 051 250 to 18 000 9
Giardia spp., cysts/100 L Geometric Mean Range n	 183 50 to 200 5	 315 8 to 13 000 9	 2 844 <250 to 18 000 9
Fecal Coliform, cfu/100 mL Geometric Mean Range N	 9 <10 to 30 5	 24 <10 to 110 10	 54 <10 to 200 9
Escherichia coli, cfu/100 mL Geometric Mean Range N	 8 <10 to 30 5	 20 <10 to 90 10	 44 <10to150 9
Turbidity, NTU Mean Range N	 8.1 1.99 to 22 5	 231 1.9 to 1 159 9	 487 46 to 2 000 9

*Data collected from April 10 to April 30, 1999. Beef density estimates (animals/ha) within watersheds: wildlife 0 to 0.17, medium beef cattle 0.18 to 0.87, high beef cattle 0.88 to 1.0, high agriculture 1.01 to 1.95
NTU = nephalometric turbidity unit

except for the geometric mean of *Giardia* spp. concentration data for both wildlife and high beef cattle sub-watersheds. However, the geometric mean of the *Giardia* spp. concentration data for the fall low flow period of 1998 was below those during the summer rainstorm flow periods of 1998. The arithmetic mean of all turbidity data during the fall low-flow period of 1998 was well below the 150 NTU limit.

The *Cryptosporidium* spp. and *Giardia* spp. concentration data is highly variable for each watershed classification during the different seasons. The *Cryptosporidium* spp. concentration was higher than the *Giardia* spp. concentration in Spring 1998, and Spring and Summer 1999. However, in the fall of 1998, the *Giardia* spp. concentrations were higher than the *Cryptosporidium* spp. concentrations. Wallis et al. (1996) report in their study that *Giardia* spp. cysts are commonly found in raw surface waters, and that *Cryptosporidium* spp. oocysts are less common than *Giardia* spp. cysts, in Canada. Our findings suggest that both are prevalent in the NSR basin raw surface water, and at times, *Cryptosporidium* spp. oocysts are found in substantially higher concentrations than *Giardia* spp. cysts.

4.4 Wastewater Treatment Plant and Sewage Treatment Lagoon Effluent Data Analysis

The WWTP and STL effluent concentration and water quality parameter data can be found in Appendix G. Again, the protozoan and microbiological data were log-normally distributed, and therefore the geometric means of the WWTP and STL

concentration data for *Cryptosporidium* spp., *Giardia* spp., Fecal coliform and *Escherichia coli* were calculated. The turbidity data were normally distributed, and therefore the arithmetic means were calculated. These data are shown in Tables 4.6 and 4.7. The total monthly effluent flows from the WWTPs in the NSR basin are shown in Appendix H.

The WWTP data shows the arithmetic mean of all turbidity data is below the 150 NTU limit. The Rocky Mountain House WWTP has the highest arithmetic mean of turbidity data, however it is not substantially greater than the other three plants. The geometric mean of fecal coliform and *Escherichia coli* data is largest at the Rocky Mountain House WWTP, this is not surprising as the Rocky Mountain House WWTP is the only plant that does not practice chemical microorganism reduction its effluent prior to discharge. The values are one to two orders of magnitude greater than at the other WWTPs. The geometric mean of *Cryptosporidium* spp. and *Giardia* spp. data are largest at the Gold Bar WWTP, 1 517, and 28 521 (oo)cysts/ 100 L. The Gold Bar WWTP has a design capacity one to two orders of magnitude greater than the other three WWTP, and it serves a population two orders of magnitude greater than the other three plants. The geometric mean of *Giardia* spp. concentration data at the Devon WWTP, 17 138 cysts/100 L, is substantially higher than that at the Drayton Valley and Rocky Mountain House WWTPs, 1 928, and 3 398 cysts/100 L, respectively. The geometric mean of *Giardia* spp. concentration data at the Devon and Gold

Table 4.6 Geometric Mean and Ranges of *Cryptosporidium* spp., *Giardia* spp., Fecal coliform, and *E. coli* and Arithmetic Mean of Turbidity at the Wastewater Treatment Plants in the North Saskatchewan River Basin, Upstream of and including the City of Edmonton for Effluent in 1998 and 1999

Sample Source	Rocky Mountain House WWTP	Drayton Valley WWTP	Devon WWTP	Goldbar WWTP
Cryptosporidium spp., oocysts/100 L Geometric Mean Range n	1 014 190 to 3 800 10	365 <100 to 1 200 10	1 089 <160 to <180 000 10	1 517 <150 to 8 900 9
Giardia spp., cysts/100 L Geometric Mean Range n	3 398 <250 to 42 000 10	1 928 100 to 27 000 10	17 138 900 to 65 000 10	28 521 8 100 to 56 000 9
Fecal Coliform, cfu/100 mL Geometric Mean Range n	754 30 to 1 200 000 10	27 <10 to 600 7	4 <4 to <91 10	36 10 to 110 9
Escherichia coli, cfu/100 mL Geometric Mean Range n	540 10 to 1 000 000 10	19 <10 to 470 10	6 <10 to 30 10	36 1 to 100 9
Turbidity, NTU Arithmetic Mean Range n	15 4.2 to 31.5 10	7 2.4 to 16.3 10	7 3.9 to 10.7 10	5 2.3 to 7.08 9

Data is for April 7, 1998 to November 25, 1999
cfu = coliform forming units, NTU = nephalometric turbidity units

Table 4.7 Geometric Mean and Ranges of *Cryptosporidium* spp., *Giardia* spp., Fecal coliform, and *E. coli* and Arithmetic Mean of Turbidity at the Sewage Lagoons in the North Saskatchewan River Basin, Upstream of the City of Edmonton for Effluent in 1998 and 1999

Sample Source	Alderflats	Breton	Calmar	Rocky Rapids	Sunnybrook	Thorsby
Cryptosporidium spp. oocysts, #/100 L						
Geometric Mean	3 200	83	<250	1 300	2 250	1 000
Range						
n	1	1	1	1	1	1
Giardia spp. cysts, #/100 L						
Geometric Mean	3 200	83	<250	1 300	<850	500
Range						
n	1	1	1	1	1	1
Fecal Coliform, cfu/100 mL						
Geometric Mean	5	5	20	10	1 100	2.6
Range						
n	1	1	1	1	1	1
Escherichia coli, cfu/100 mL						
Geometric Mean	5	5	10	10	480	5
Range						
n	1	1	1	1	1	1
Turbidity, NTU						
Arithmetic Mean	39.2	0.96	1.44	15.15	16.3	5
Range						
n	1	1	1	1	1	1

Continued on Next Page

Sample Source	Tomahawk (main)	Tomahawk (school)	Violet Grove	Warburg	Winfield
Cryptosporidium spp. oocysts, #/100 L Geometric Mean Range n	1 343 <880 to 3 700 4	1 222 830 to 1 800 2	310 1	137 332 82 000 to 200 000 2	1 500 1
Giardia spp. cysts, #/100 L Geometric Mean Range n	97 986 5 000 to 200 000 4	2 500 2 500 to 7 000 2	310 1	3 240 750 to 14 000 2	6 000 1
Fecal Coliform Bacteria, cfu/100 mL Geometric Mean Range n	32 601 11 000 to 63 000 4	170 170 to 1 600 2	5 600 1	14 422 6 500 to 32 000 2	40 000 1
Escherichia coli, cfu/100 mL Geometric Mean Range n	27 102 7 900 to 63 000 4	170 170 to 700 2	4 500 1	12 186 5 500 to 27 000 2	40 000 1
Turbidity, NTU Arithmetic Mean Range n	120 22 to 227 4	40 49.5 to 30.2 2	75.2 1	21 19.6 to 23.1 2	16.3 1

Data is for April 6, 1998 to November 01, 1999
cfu = coliform forming units, NTU = nephalometric turbidity units

Bar WWTP are substantially greater than the other two WWTPs. The geometric mean of *Cryptosporidium* spp. concentration data is in the same order of magnitude for all four WWTPs, even with the difference in populations each plant services.

The geometric means of the fecal coliform data for the Winfield, Tomahawk (main), and Warburg STL, 40 000, 32 601, and 14 422 cfu/100 mL, respectively, were substantially higher than all other STLs. As well, the *Escherichia coli* data for Winfield, Tomahawk (main), and Warburg STL, 40 000, 27 102, 12 186 cfu/100 mL respectively, were significantly higher than all other STLs. The fecal coliform and *Escherichia coli* data for these three STLs were significantly higher than the WWTPs that continuously discharge into the NSR. The highest geometric means for WWTP fecal coliform and *Escherichia coli* came from the Rocky Mountain House WWTP and were 754, and 540 cfu/100 mL, respectively.

The highest geometric mean for *Cryptosporidium* spp. concentration data was observed at the Warburg STL at 137 332 oocysts/100 L. This value is substantially higher than all other lagoons, with the next three highest geometric mean values being 3 200, 2 250, and 1 500 oocysts/100 L at the Alderflats, Sunnybrook, and Winfield STLs, respectively. The concentration value observed at the Warburg STL is two orders of magnitude higher than the values observed at the WWTPs, with the highest geometric mean being observed at the Gold Bar WWTP at 1 517 oocysts/100 L.

The highest geometric mean of *Giardia* spp. concentration data was observed at the Tomahawk (main) STL (97 986 cysts/100 L). This value was at least one order of magnitude greater than all other STL concentration data. The next three highest geometric mean values were observed at the Winfield, Warburg, and Alderflats STL and were 6 000, 3 240, and 3 200 cysts/100 L, respectively. The concentration observed at the Tomahawk (main) STL is higher than that observed at the Gold Bar and Devon WWTPs, 28 521, and 17 138 cysts/100 L, respectively. The arithmetic mean of turbidity data from all STLs was well below the 150 NTU limit set by the ICR method.

The concentrations of *Cryptosporidium* spp., *Giardia* spp., fecal coliform, and *Escherichia coli* being discharged into the creeks and rivers flowing into the NSR by STLs are substantially higher than those being discharged by the WWTPs.

Table 4.8 Rocky Mountain House WWTP Effluent Monthly Loading Summary 1999

Month	Total Monthly Flow, L	*Cryptosporidium* spp. Concentration, # oocysts/100L	*Cryptosporidium* spp. Load, # oocysts/month	*Giardia* spp. Concentration, # cysts/100L	*Giardia* spp. Load, # cysts/month
January	7.19E+07	3 800	2.73E+09	24 000	1.73E+10
February*	6.33E+07	2 615.3	1.66E+09	31 749	2.01E+10
March	6.83E+07	1 800	1.23E+09	42 000	2.87E+10
April*	8.38E+07	1 800	1.51E+09	13 900	1.17E+10
May@	8.26E+07	1 800	1.49E+09	4 600	3.80E+09
June@*	8.45E+07	1 990.0	1.68E+09	4 550	3.84E+09
July@	1.06E+08	2 200	2.34E+09	4 500	4.78E+09
August@*	8.06E+07	2 437.2	1.97E+09	1 219	9.83E+08
September	6.69E+07	2 700	1.81E+09	330	2.21E+08
October*	5.41E+07	1 423.0	7.70E+08	1 573	8.51E+08
November	4.93E+07	750	3.70E+08	7 500	3.70E+09
December+	4.35E+07	750	3.26E+08	7 500	3.26E+09

@ flow meter malfunction at WWTP and no flow data available for 1999, therefore 1998 data was used.

* *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by using the values measured in the month immediately prior or after sample month

\+ *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by calculating the geometric mean of the months immediately before and after sample month

Table 4.9 Drayton Valley WWTP Effluent Loading Summary for 1999

Month	Total Monthly Flow, L	*Cryptosporidium* spp. Concentration, # oocysts/100L	*Cryptosporidium* spp. Load, # oocysts/month	*Giardia* spp. Concentration, # cysts/100L	*Giardia* spp. Load, # cysts/month
January	1.38E+08	440	6.05E+08	27 000	3.72E+10
February*	1.13E+08	265.3	3.00E+08	25 981	2.94E+10
March	1.47E+08	160	2.35E+08	25 000	3.66E+10
April*	1.92E+08	257.7	4.94E+08	3 221	6.18E+09
May	1.85E+08	415	7.66E+08	415	7.66E+08
June*	1.58E+08	144.0	2.28E+08	204	3.22E+08
July	1.78E+08	50	8.88E+07	100	1.78E+08
August	1.56E+08	170	2.65E+08	420	6.54E+08
September*	1.39E+08	451.7	6.28E+08	2 750	3.82E+09
October*	1.82E+08	451.7	8.24E+08	2 750	5.01E+09
November	1.40E+08	1 200	1.68E+09	18 000	2.52E+10
December+	1.09E+08	1 200	1.31E+09	18 000	1.96E+10

* *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by using the values measured in the month immediately prior or after sample month

+ *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by calculating the geometric mean of the months immediately before and after sample month

Table 4.10 Devon WWTP Effluent Loading Summary for 1999

Month	Total Monthly Flow, L	*Cryptosporidium* spp. Concentration, # oocysts/100L	*Cryptosporidium* spp. Load, # oocysts/month	*Giardia* spp. Concentration, # cysts/100L	*Giardia* spp. Load, # cysts/month
January[+]	5.45E+07	900	4.91E+08	90 000	4.91E+10
February	5.00E+07	900	4.50E+08	90 000	4.50E+10
March	5.86E+07	250	1.47E+08	65 000	3.81E+10
April*	6.05E+07	353.6	2.14E+08	58 138	3.52E+10
May	7.20E+07	500	3.60E+08	52 000	3.74E+10
June*	6.77E+07	353.6	2.39E+08	20 649	1.40E+10
July	7.79E+07	250	1.95E+08	8 200	6.39E+09
August*	6.61E+07	724.6	4.79E+08	11 454	7.58E+09
September	5.99E+07	2 100	1.26E+09	16 000	9.58E+09
October*	5.84E+07	409.9	2.39E+08	20 396	1.19E+10
November	5.70E+07	80	4.56E+07	26 000	1.48E+10
December[+]	5.79E+07	80	4.63E+07	26 000	1.50E+10

* *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by using the values measured in the month immediately prior or after sample month

[+] *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by calculating the geometric mean of the months immediately before and after sample month

Table 4.11 Gold Bar WWTP Effluent Loadings for 1999

Month	Total Monthly Flow, L	*Cryptosporidium* spp. Concentration, # oocysts/100L	*Cryptosporidium* spp. Load, # oocysts/month	*Giardia* spp. Concentration, # cysts/100L	*Giardia* spp. Load, # cysts/month
January*	6.70E+09	8 900	5.96E+11	48 000	3.22E+12
February	6.19E+09	8 900	5.51E+11	48 000	2.97E+12
March	7.70E+09	900	6.93E+10	55 000	4.24E+12
April+	7.55E+09	848.5	6.41E+10	50 843	3.84E+12
May	8.72E+09	800	6.98E+10	47 000	4.10E+12
June+	8.12E+09	1 200	9.75E+10	21 131	1.72E+12
July	8.72E+09	1 800	1.57E+11	9 500	8.29E+11
August+	8.32E+09	474.3	3.94E+10	10 223	8.50E+11
September	7.73E+09	125	9.66E+09	11 000	8.50E+11
October+	7.40E+09	201.6	1.49E+10	18 762	1.39E+12
November	6.71E+09	325	2.18E+10	32 000	2.15E+12
December*	6.70E+09	325	2.18E+10	32 000	2.14E+12

* *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by using the values measured in the month immediately prior or after sample month

\+ *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by calculating the geometric mean of the months immediately before and after sample month

Table 4.12 Sewage Treatment Lagoon Effluent Loadings for 1999

STL Lagoon	Discharge Dates	Total Flow (L)	*Cryptosporidium* spp. Concentration (# cysts/100 L)	*Cryptosporidium* spp. Load (# cysts)	*Giardia* spp. Concentration (# cysts/100 L)	*Giardia* spp. Load (# cysts)
Alderflats	Oct. 18-21	1.50E+07	3 200	4.80E+08	3 200	4.80E+08
Breton	Oct. 15-29	5.23E+07	83	4.34E+07	83	4.34E+07
Buck Creek*	June 15-30	1.21E+07	1 693	2.05E+08	2 287	2.77E+08
Calmar	Aug. 3-16	1.83E+08	250	4.56E+08	250	4.56E+08
Rocky Rapids	May 4-7	4.86E+07	1 300	6.32E+08	1 300	6.32E+08
Sunnybrook**	Oct 18-22	6.00E+06	2 250	1.35E+08	850	5.10E+07
Thorsby	Oct. 12-19	1.09E+08	1 000	1.09E+09	500	5.46E+08
Tomahawk (main)	April 7-8	4.48E+06	3 700	1.66E+08	200 000	8.96E+09
Tomahawk (main)	Nov. 1-4	6.58E+06	1 760	1.16E+08	48 000	3.16E+09
Tomahawk (school)	Nov. 1-2	1.70E+06	2 500	4.25E+07	830	1.41E+07
Violet Grove	April 8-12	2.25E+07	1 900	4.28E+08	310	6.98E+07
Warburg	April 13- May 4	9.50E+07	82 000	7.79E+10	14 000	1.33E+10
Winfield	Oct. 21-25	1.20E+07	1 500	1.80E+08	6 000	7.20E+08

*Lagoon effluent was not sampled, *Cryptosporidium* spp. and *Giardia* spp. concentrations estimated by taking the geometric mean of all other sampled lagoons, based on 1999 data. Flow data is 1999 data.

** Lagoon effluent was not sampled, *Cryptosporidium* spp. and *Giardia* spp. loading and lagoon flow is estimated by the values measured in 1998 at same lagoon.

The loadings of the WWTPs and the STLs were calculated for 1999 data and are shown in Tables 4.8 to 4.12. The loads for the WWTPs were calculated by multiplying the total monthly flow by the concentration value obtained for sampling that month. WWTP sampling was performed every second month in 1999 and therefore there were only six actual concentration data sets. Each month that sampling was not performed in had a geometric mean of the month before and after it calculated and that was the concentration value used for that month.

For the STLs, the concentration value obtained while sampling the effluent was multiplied by the total volume discharged by the lagoon. The total volume discharged was called the total flow (L) of the lagoon and it was obtained directly from the lagoon operators. Most lagoon operators had a good understanding of the volume that was discharged, however, a few were rough estimates of 90% of the capacity of the lagoon.

Warburg STL discharged from April 13 to May 4th in 1999. The total *Giardia* spp. loading ($1.33x10^{10}$ cysts) from the Warburg STL was in the same order of magnitude as the total monthly loadings from either the Rocky Mountain House, Drayton Valley or Devon WWTPs ($1.17x10^{10}$, $6.18x10^{9}$, and $3.52x10^{10}$ cysts/month, respectively) for April. The *Cryptosporidium* spp. loading from the Warburg STL ($7.79x10^{10}$ oocysts) was one to two orders of magnitude greater than the total monthly loading observed at either the Rocky Mountain House, Drayton Valley or Devon WWTPs ($1.51x10^{9}$, $4.94x10^{8}$, and $2.14x10^{8}$ oocysts/month, respectively) for the month of April.

The combined loading of the April 7-8th and the November 1-4th releases of the Tomahawk (main) STL result in a *Cryptosporidium* spp. loading of 2.82×10^8 oocysts, and a *Giardia* spp. loading of 1.21×10^{10} cysts. This *Giardia* spp. loading value is very similar to that of the Warburg STL. All other STL *Giardia* spp. loadings for 1999 are at least two orders of magnitude lower than the Warburg and the combined Tomahawk (main) STL *Giardia* spp. load.

The Thorsby STL has the second highest *Cryptosporidium* spp. loading at 1.09×10^9 oocysts. All other STL *Cryptosporidium* spp. loadings, including the combined Tomahawk (main) discharges, are at least one order of magnitude lower than the Thorsby STL and at least two orders of magnitude lower than the Warburg STL *Cryptosporidium* spp. load.

Wallis et al. (1996) found that of the 164 raw sewage samples they analyzed, 72.6% were *Giardia* spp. positive and only 6.1% were *Cryptosporidium* spp. positive. The data presented in this study suggest that both *Cryptosporidium* spp. and *Giardia* spp. are present at high concentrations in sewage effluent samples in the NSR basin.

The Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems (Alberta Environmental Protection 1997) indicates that in Alberta, sewage treatment lagoons should be discharged once a year between late spring and

fall. *The Standards* also states that spring discharges may be allowed only under exceptional circumstances, and that the storage cell capacity should for 365 days. For the lagoons to work properly and effectively treat the sewage effluent (remove pathogens and bacteria), the lagoons require the full 365 day holding time combined with fall releases. The Tomahawk (main) lagoon, which discharges twice a year on a regular basis, should be upgraded to a fully 365 day storage capacity lagoon, and should be permitted to once per year during the fall. The Warburg STL routinely discharges in April/May, and should be permitted to discharge in the fall only. It has been shown that fall discharges significantly reduce the pathogen and bacteria concentrations in sewage lagoon effluent.

4.5 Water Treatment Plant Data Analysis

The NSR source water was sampled at each WTP (Rocky Mountain House, Drayton Valley, Thorsby and Devon) upstream of the City of Edmonton every two months, except for the Thorsby WTP which was only sampled twice, during 1999. The concentration data are shown in Table 4.13.

The *Giardia* spp. concentrations for the WTPs were log-normally distributed, and therefore, the geometric means of the *Giardia* spp. concentrations were calculated. *The Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems for Alberta* (Alberta Environmental Protection, 1997), report recommended *Giardia* spp. log reduction based on the geometric means of raw water *Giardia* spp.

levels. Table 4.14 shows the recommended *Giardia* spp. reduction levels for different geometric means of raw water *Giardia* spp. levels.

Figures 4.8 to 4.11 show the *Giardia* spp. concentration data for each WTP as well as the geometric mean of the concentration data for the 1999 year. The 3-log, 4-log, and 5-log reduction lines are shown on each graph. The Devon WTP has a geometric mean of greater than 100 cysts/100 L for *Giardia* spp. concentration in its raw water. This indicates that the WTP should maintain a greater than 5-log reduction in *Giardia* spp. concentration, a large feat for a small municipal WTP. The other three WTPs upstream of the City of Edmonton, Rocky Mountain House, Thorsby, and Devon WTPs all had geometric means greater than 10 and less than 100 cysts/100 L, and therefore should maintain between 4-log and 5-log reduction in *Giardia* spp. concentration. The sampling crews were unable to sample the source water at these WTPs upstream of Edmonton during spring runoff. It is hypothesized that these samples would contain the highest concentrations of *Cryptosporidium* spp. and *Giardia* spp. Meaning, that the yearly *Giardia* spp. concentration geometric mean for 1999 would be greater than 100 cysts/100 L. Indicating that these rural WTPs upstream of Edmonton should be aiming for a *Giardia* spp. concentration reduction of greater than 5 log.

Table 4.13 Concentration Data From Water Treatment Plants in the North Saskatchewan River Basin Upstream of the City of Edmonton, 1999

Water Treatment Plant	Date Sampled	*Cryptosporidium* spp. Concentration (oocysts/100 L)	*Giardia* spp. Concentration (cysts/100 L)	Geometric Mean *Giardia* spp. Concentration (cysts/100 L)
Rocky Mountain House	28-Jan-99	14	64	55.0
Rocky Mountain House	17-Mar-99	47	23	
Rocky Mountain House	13-May-99	21	*7.1*	
Rocky Mountain House	14-Jul-99	800	*200*	
Rocky Mountain House	8-Sep-99	*21*	120	
Rocky Mountain House	24-Nov-99	*8.3*	110	
Drayton Valley	26-Jan-99	25	*25*	54.8
Drayton Valley	16-Mar-99	*13*	*13*	
Drayton Valley	11-May-99	*50*	*50*	
Drayton Valley	12-Jul-99	*250*	*250*	
Drayton Valley	31-Aug-99	67	67	
Drayton Valley	25-Nov-99	5	100	
Devon	2-Feb-99	25	25	113.2
Devon	18-Mar-99	39	*39*	
Devon	12-May-99	67	67	
Devon	6-Jul-99	*1 600*	*1 600*	
Devon	1-Sep-99	*72*	*72*	
Devon	23-Nov-99	8.3	280	
Thorsby	29-Jan-99	*6.7*	*6.7*	23.6
Thorsby	7-Oct-99	*83*	83	

Italicized numbers are below detection limit data (censored data) for Cryptosporidium spp. *and Giardia* spp. *and are reported as full detection limit.* (47.5% (19/40) of samples were below detection limit for raw WTP source water sampling)

Table 4.14: Alberta Environmental Protection Level of *Giardia* spp. Reduction

Raw Water *Giardia* spp. Levels*	Recommended *Giardia* spp. Log Reduction
< 1 cyst/100 L	3-log
1 cyst/100 L – 10 cysts/100 L	3-log – 4-log
10 cysts/100 L – 100 cysts/100 L	4-log – 5-log
> 100 cysts/100 L	> 5-log

*levels are based on geometric means of concentration data

The finished water from the WTPs upstream of Edmonton was sampled at the same time that the raw water was sampled, except for the Thorsby WTP January, 1999 sample run where no finished water sample was obtained (Table 4.15). All finished water concentration values shown in Table 4.15 are censored data, except the Devon WTP February 2, 1999 *Giardia* spp. concentration value of 0.2 cysts/100 L, which was a detected value. The other censored data values have been replaced with the full detection limit for the purpose of analysis.

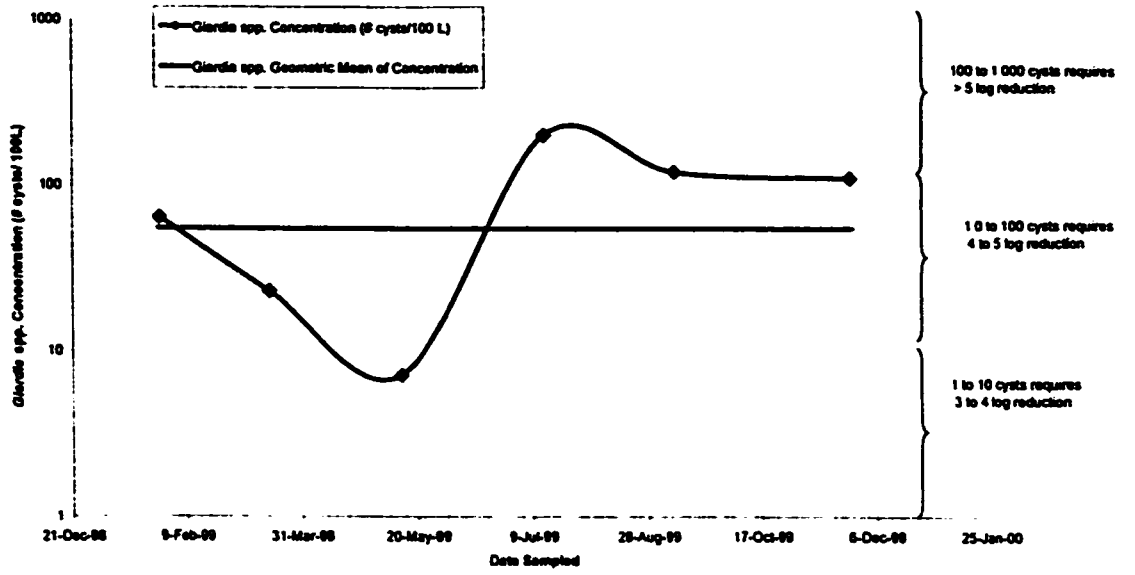

Figure 4.8: Rocky Mountain House WTP Raw Water *Giardia* spp. Concentration, 1999

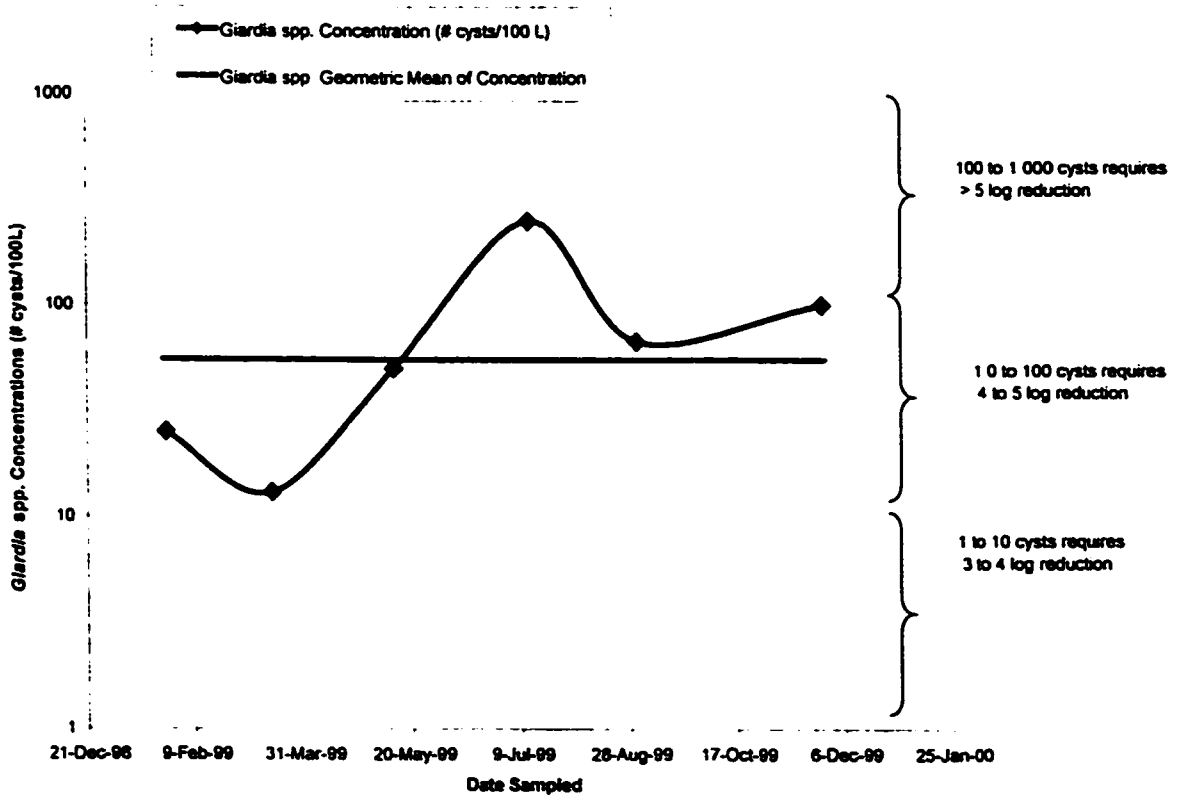

Figure 4.9: Drayton Valley WTP Raw Water *Giardia* spp. Concentration, 1999

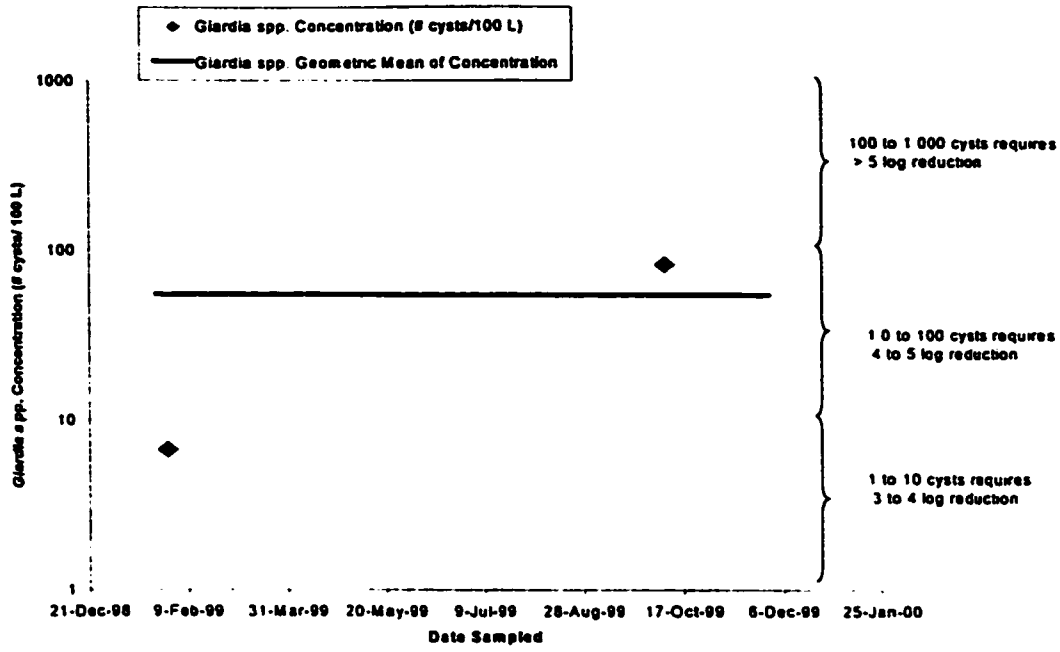

Figure 4.10: Thorsby WTP Raw Water *Giardia* spp. Concentration, 1999

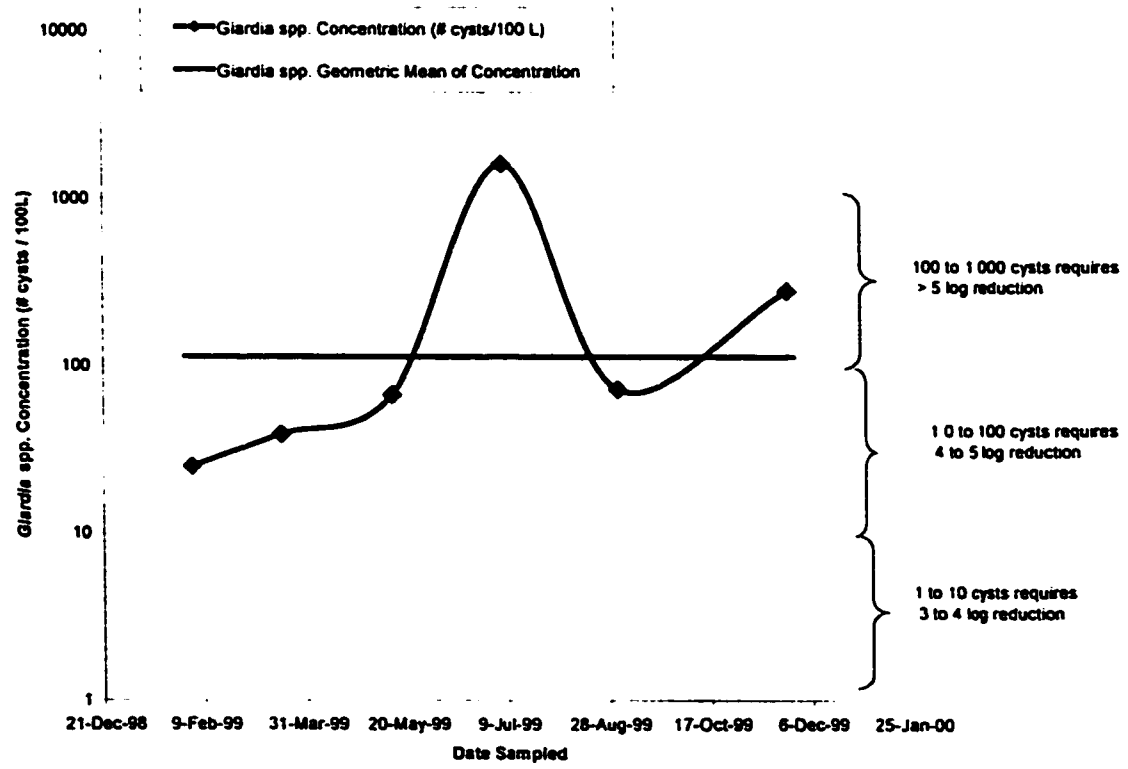

Figure 4.11: Devon WTP Raw Water *Giardia* spp. Concentration, 1999

Table 4.15: Finished Water and Raw Water Concentration Data for Water Treatment Plants in the North Saskatchewan River Basin, Upstream of Edmonton, 1999

		Cryptosporidium spp. Concentration in Raw Water (oocysts/100 L)	*Cryptosporidium* spp. Concentration in Finished Water (oocysts/100 L)	*Giardia* spp. Concentration in Raw Water (cysts/100 L)	*Giardia* spp. Concentration in Finished Water (cysts/ 100 L)
Rocky Mountain House	28-Jan-99	14	*0.1*	64	*0.1*
Rocky Mountain House	17-Mar-99	47	*0.1*	23	*0.1*
Rocky Mountain House	13-May-99	21	*0.1*	*7.1*	*0.1*
Rocky Mountain House	14-Jul-99	800	*0.1*	*200*	*0.1*
Rocky Mountain House	08-Sep-99	*21*	*0.1*	120	*0.1*
Rocky Mountain House	24-Nov-99	*8.3*	*0.1*	110	*0.1*
Drayton Valley	26-Jan-99	25	*0.1*	*25*	*0.1*
Drayton Valley	16-Mar-99	*13*	*0.1*	*13*	*0.1*
Drayton Valley	11-May-99	*50*	*2.5*	*50*	*2.5*
Drayton Valley*	07-Jul-99	*250*	*0.1*	*250*	*0.1*
Drayton Valley	31-Aug-99	67	*0.1*	67	*0.1*
Drayton Valley	25-Nov-99	5	*0.1*	100	*0.1*
Devon	02-Feb-99	25	*0.1*	25	0.2
Devon	18-Mar-99	39	*0.1*	*39*	*0.1*
Devon	12-May-99	67	*0.8*	67	*0.8*
Devon	06-Jul-99	*1 600*	*0.1*	*1 600*	*0.1*
Devon	01-Sep-99	*72*	*0.1*	*72*	*0.1*
Devon	23-Nov-99	8.3	*0.1*	280	*0.1*
Thorsby	07-Oct-99	*6.7*	*1.3*	*6.7*	*1.3*

Italicized numbers are below detection limit values for Cryptosporidium spp. and Giardia spp. and have been reported as full detection limit (47.4% (18/38) of raw water samples and 97.4% (37/38) of finished water samples were below detection limit.)

4.6 Comparative Watershed Study Data Analysis

The *Cryptosporidium* spp. and *Giardia* spp. concentration data collected as part of the comparative sub-watershed study in 1999 are shown in Appendix A. For the wildlife sub-watersheds, Baptiste River and Nordegg River, loading data from their mouth sites have been plotted to compare the two sites with each other to see if there was a substantial difference between the two watersheds (Figures 4.12 and 4.13). The loading data were obtained by multiplying the concentration data by the instantaneous flow (m^3/s) that was measured at the time of the sampling in the field. The *Cryptosporidium* spp. and *Giardia* spp. loads ((oo)cyst/day) were calculated for the wildlife sub-watersheds, Baptiste River and Nordegg River (Figures 4.12 and 4.13), the high beef cattle sub-watersheds, Tomahawk Creek and Mishow Creek (Figures 4.14 and 4.15), and the high agriculture sub-watersheds, Strawberry Creek and Weed Creek (Figures 4.16 and 4.17).

The wildlife sub-watersheds, Baptiste River at the mouth site and the Nordegg River at Sunchild Road site, had similar loadings for both *Cryptosporidium* spp. and *Giardia* spp. values throughout the 1999 sampling period. As well, the high beef cattle sub-watersheds, Tomahawk Creek and Mishow Creek, had very similar loadings for both *Cryptosporidium* spp. and *Giardia* spp. throughout the 1999 sampling period (Figures 4.14 and 4.15). The high agriculture sub-watersheds, Strawberry Creek and Weed Creek, had similar loading patterns for the 1999 sampling period, however, the Weed Creek loads were around one order of magnitude lower than the Strawberry Creek

loads. The higher loadings in the Strawberry Creek sub-watershed were expected as a result of its size being almost twice that of the Weed Creek sub-watershed.

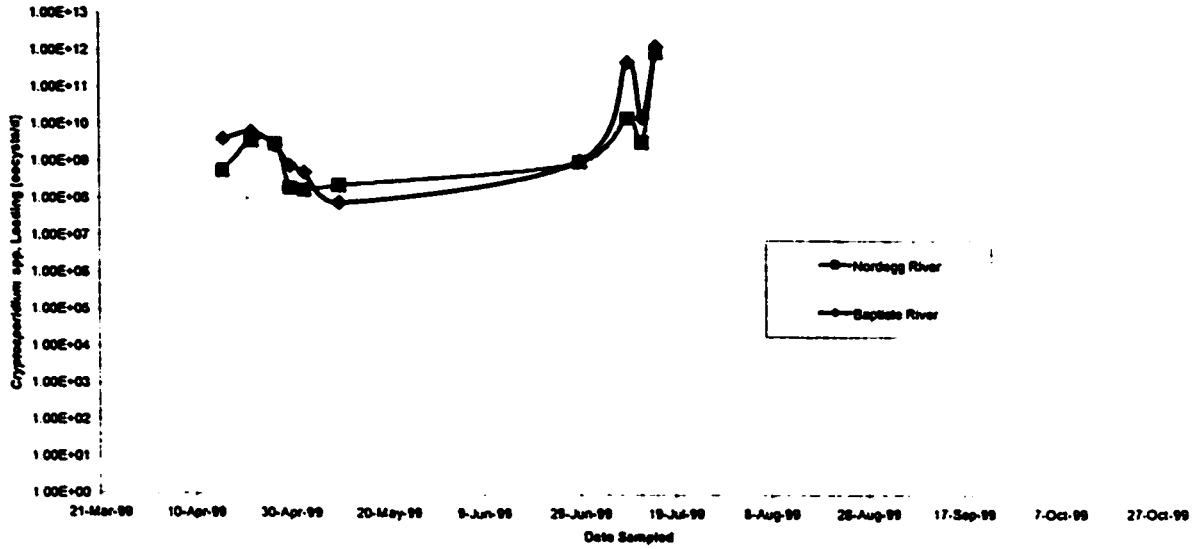

Figure 4.12: Wildlife Sub-watersheds *Cryptosporidium* spp. Loadings, 1999

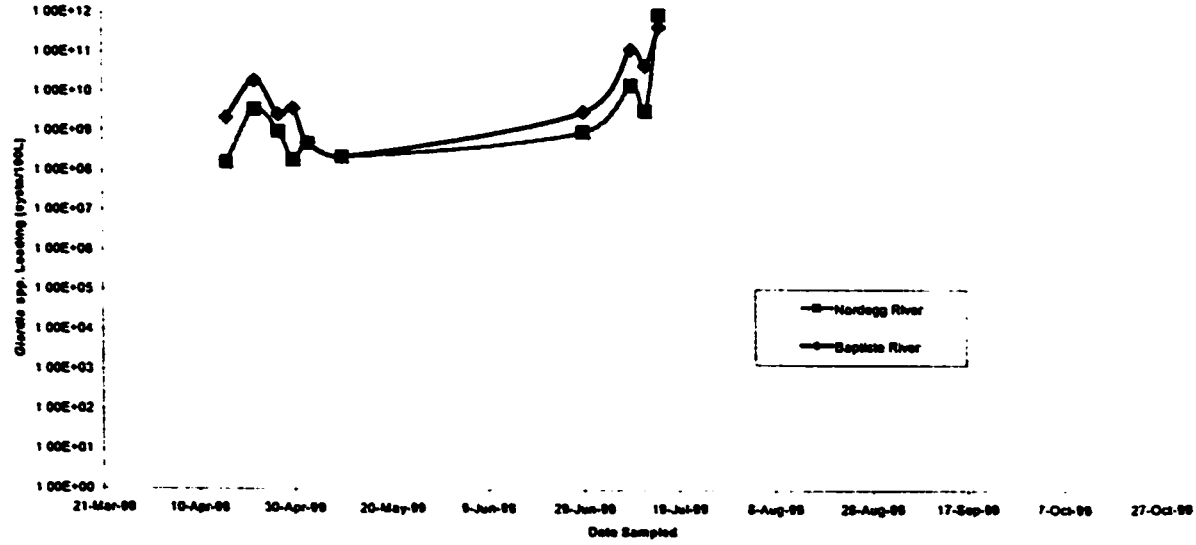

Figure 4.13: Wildlife Sub-watersheds *Giardia* spp. Loading, 1999

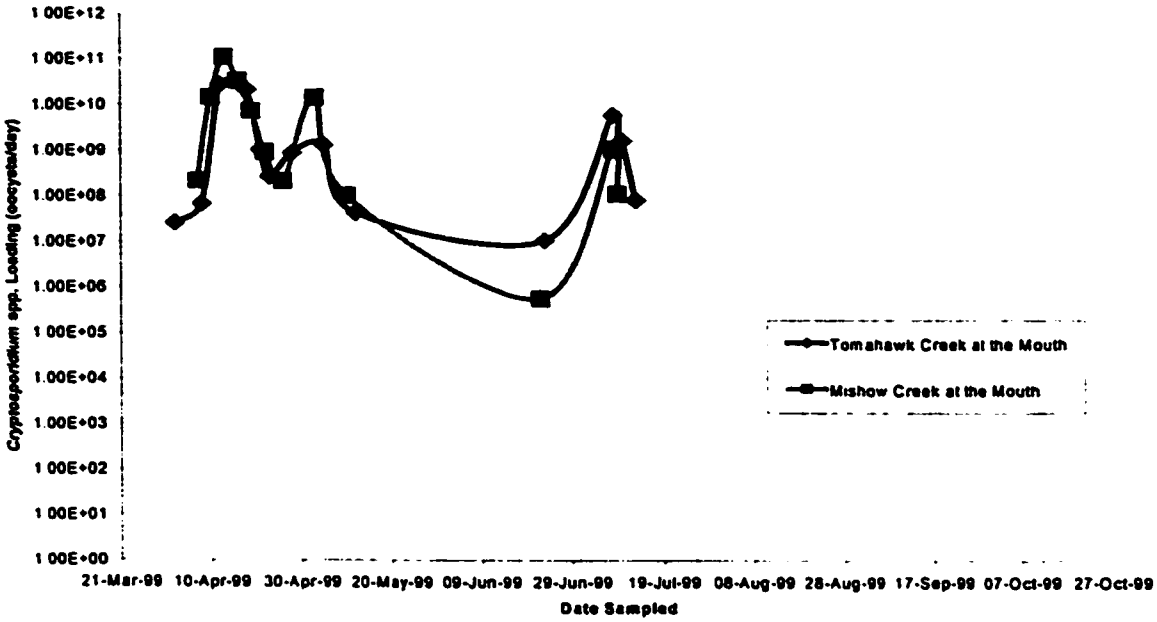

Figure 4.14: High Beef Cattle Sub-Watersheds *Cryptosporidium* spp. Loading, 1999

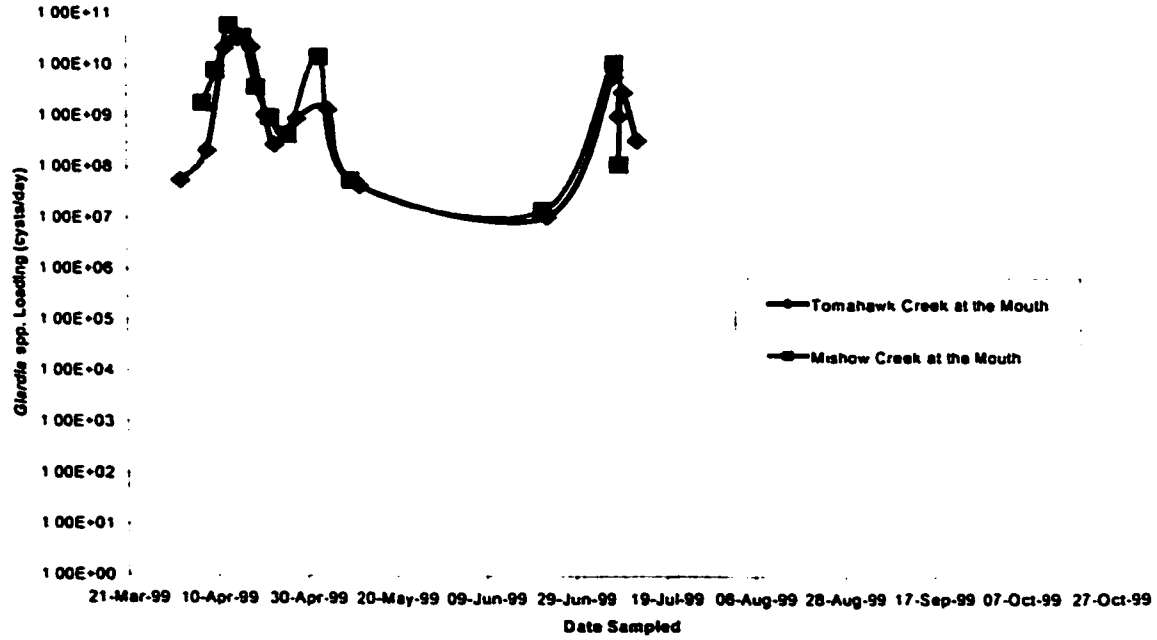

Figure 4.15: High Beef Cattle Sub-Watersheds *Giardia* spp. Loading, 1999

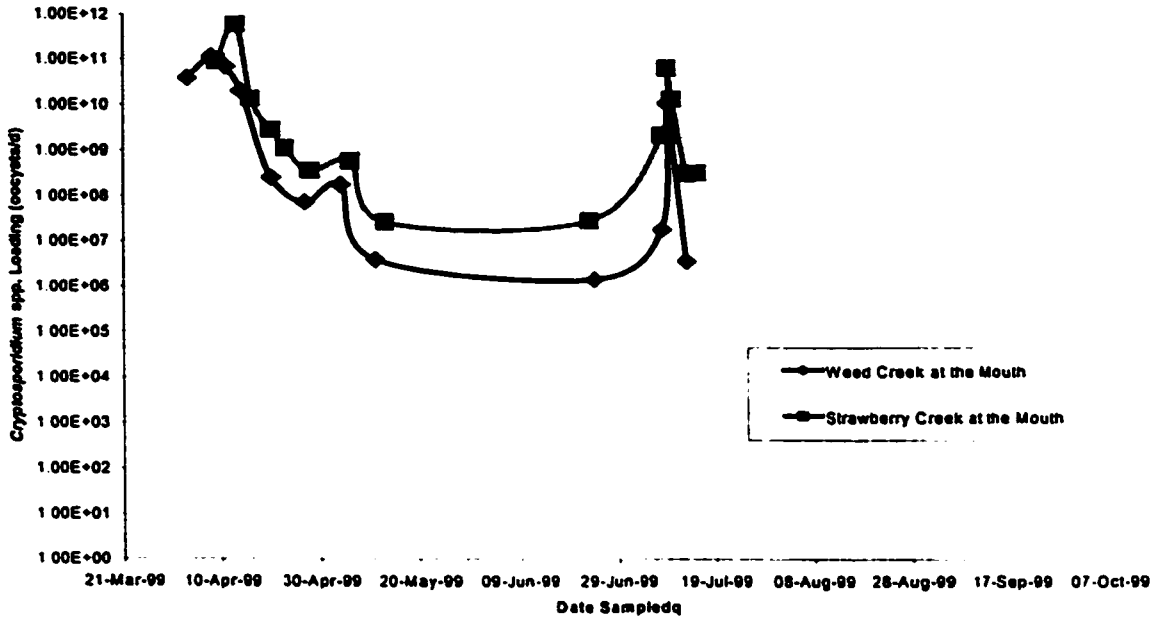

Figure 4.16: High Agriculture Sub-watersheds *Cryptosporidium* spp. Loading, 1999

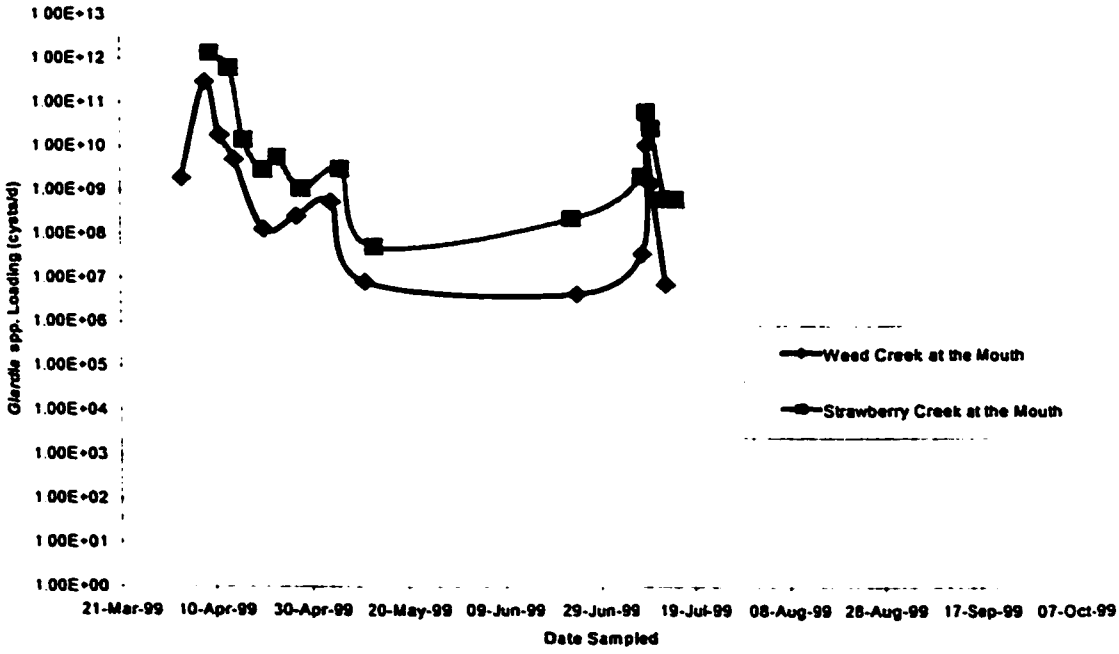

Figure 4.17: High Agriculture Sub-watersheds *Giardia* spp. Loading, 1999

4.7 Upstream/Downstream Study Data Analysis

The upstream/downstream *Cryptosporidium* spp. and *Giardia* spp. concentration data collected in 1999 are shown in Appendix I, combined with the comparative sub-watershed data. The concentration data for the three sub-watersheds that had upstream/downstream sampling performed, Weed Creek (a high agriculture sub-watershed), Tomahawk Creek, and Mishow Creek (both high beef cattle sub-watersheds) were plotted and are shown in Figures 4.18 to 4.23. The data were plotted on a three dimensional axis to show how the concentrations vary at each site near the mouth, downstream of a farm and upstream of the farms.

The Weed Creek *Cryptosporidium* spp. and *Giardia* spp. concentration data were substantially higher at the mouth during spring runoff than upstream in the creek. *Giardia* spp. was present in Weed Creek mostly during spring runoff in 1999, and only to a small extent during the summer rainstorm event in July of 1999. The concentrations of *Giardia* spp. were the substantially higher during spring runoff in 1999 for Weed Creek at the mouth. *Cryptosporidium* spp. was present for a greater length of time than *Giardia* spp. in the Weed Creek mouth samples. The concentrations of *Cryptosporidium* spp. were substantially higher during spring runoff than during the summer rainstorm event. There was no apparent difference in either *Cryptosporidium* spp. or *Giardia* spp. concentrations downstream of the participating cooperator's operation than the upstream sample.

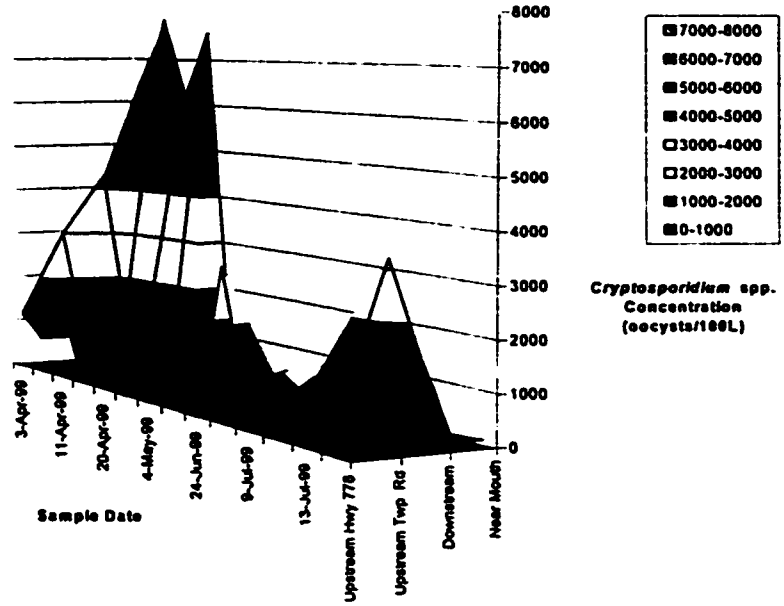

Figure 4.18 Weed Creek Sub-Watershed *Cryptosporidium* spp. Concentrations (oocysts/100L), 1999

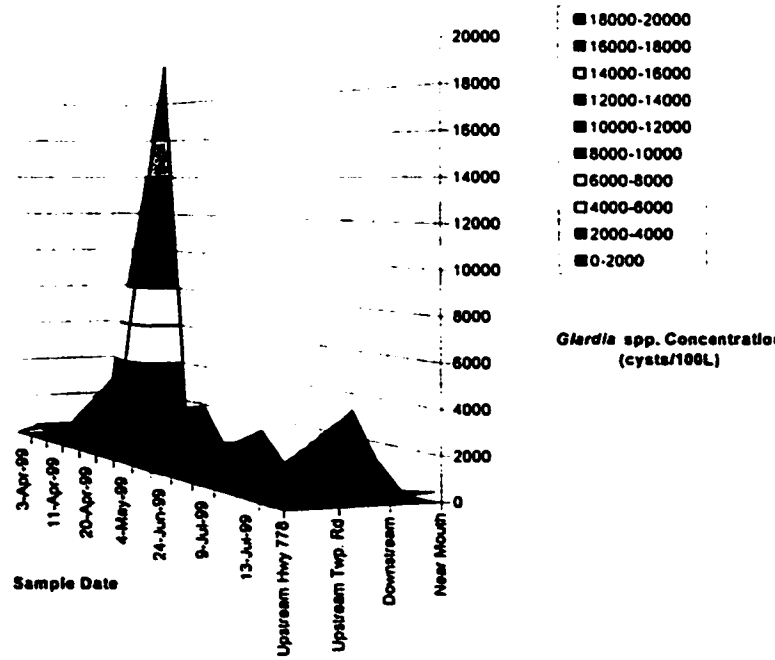

Figure 4.19 Weed Creek Sub-watershed *Giardia* spp. Concentration (cysts/100 L), 1999

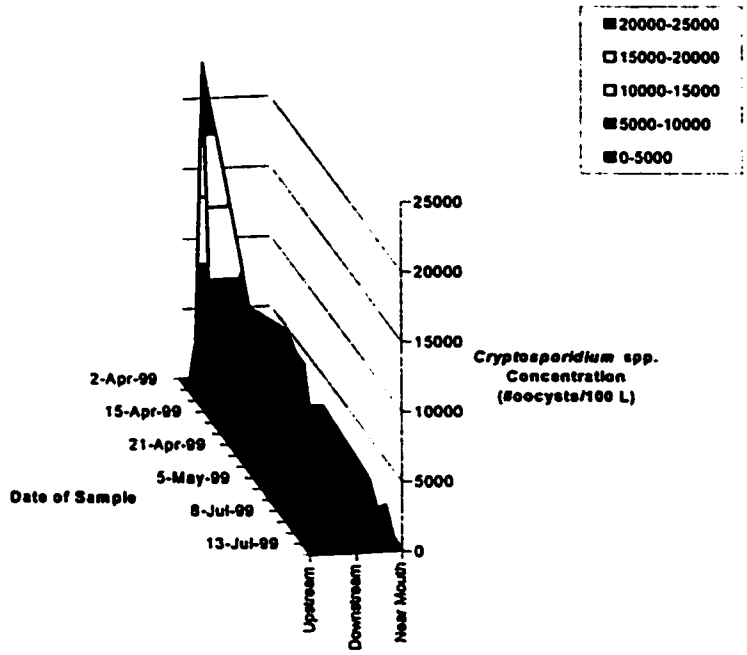

Figure 4.20 Tomahawk Creek Sub-watershed *Cryptosporidium* spp. Concentrations (oocysts/100L), 1999

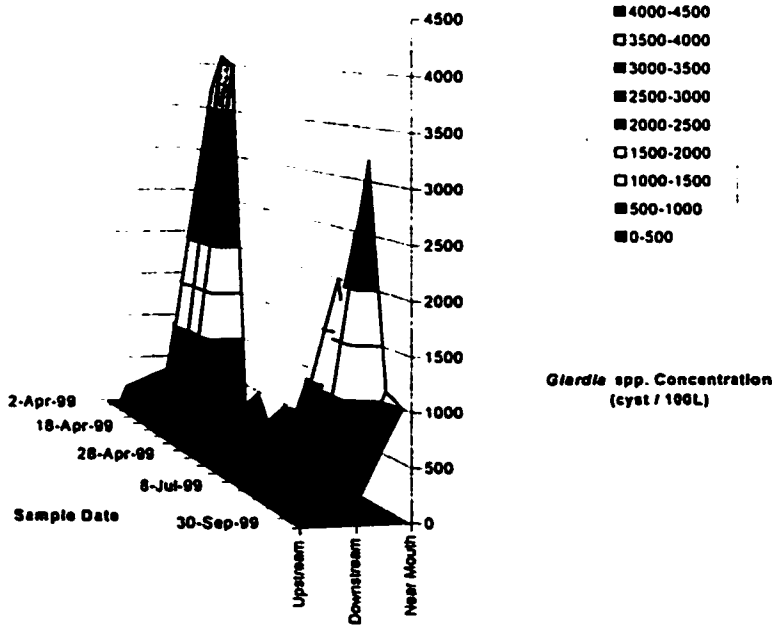

Figure 4.21 Tomahawk Creek Sub-watershed *Giardia* spp. Concentration (cysts/100 L), 1999

However, there does seem to be an apparent difference between the upstream concentrations of *Cryptosporidium* spp. and *Giardia* spp. and the concentrations at the mouth, with the mouth being substantially higher.

The Tomahawk Creek sub-watershed had substantially higher *Cryptosporidium* spp. concentration levels upstream in the creek. The values downstream of the participating cooperator and at the mouth were substantially lower during spring runoff, and either equal, or lower during summer rainstorm events. The *Cryptosporidium* spp. concentration could have been lower downstream and at the mouth due to the relatively low percent recoveries of the sampling and processing methods used. Also, since only one portion of the creek is measured, the "slug" measured upstream may have not been measured at either the downstream or mouth sampling sites. Another possible explanation is that there was a large input of water between the upstream site and the downstream and mouth sites, leading to dilution and hence a lower concentration of *Cryptosporidium* spp. being measured. The *Giardia* spp. concentrations in Tomahawk Creek were higher at the mouth than any other location in the creek. The values were highest during spring runoff, however, they were very high during late summer rainstorm events and during fall low-flow periods. Again, there is no apparent difference downstream of the participating cooperator when compared to the upstream concentration data values for *Giardia* spp. For *Cryptosporidium* spp., the values downstream of the participating cooperator were actually lower during spring runoff, and similar during all other flow periods.

The Mishow Creek sub-watershed had very high *Cryptosporidium* spp. concentration data at the mouth during spring runoff. The initial flush of spring runoff showed high values upstream, however the mouth values were substantially higher. As well, the mouth values were higher during late spring and early summer flow events. The *Giardia* spp. concentration data were significantly higher at the mouth during all flow events for Mishow Creek. The highest values were observed during late summer and fall low flow events. Again, there was no apparent difference between values downstream of the participating cooperator as compared to the concentration data obtained upstream of the farms.

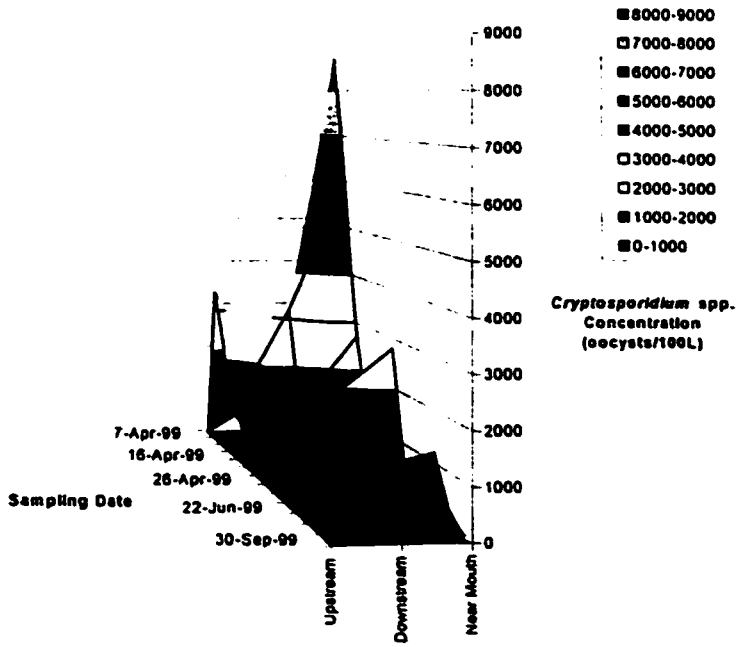

Figure 4.22 Mishow Creek Sub-Watershed *Cryptosporidium* spp. Concentration (oocysts/100L), 1999

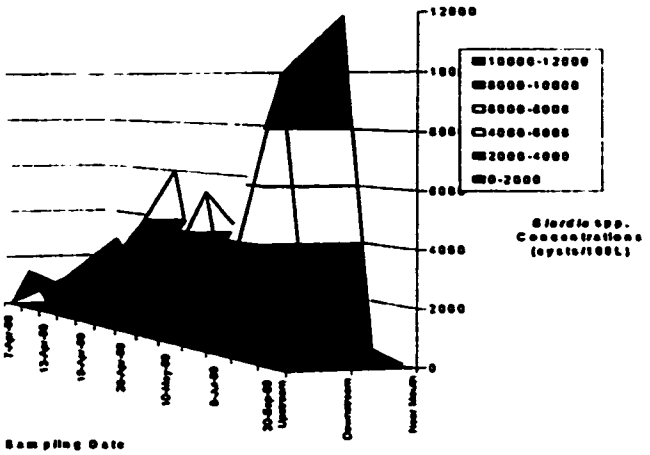

Figure 4.23 Mishow Creek Sub-Watershed *Giardia* spp. Concentration (cysts/100L), 1999

4.8 EL Smith WTP Protozoan Loading Analysis

There was long term historical *Cryptosporidium* spp. and *Giardia* spp. concentration data available for raw water from both the E.L. Smith and Rossdale WTP starting in 1992 to present. The historical concentration data is shown in Appendix J. These data were converted to loads using the flows at Edmonton, provided by Environment Canada (Appendix J). The *Cryptosporidium* spp. and *Giardia* spp. concentrations at both WTPs are shown in Figures 4.24 to 4.27.

The 1999 loadings from the WWTP upstream of Edmonton (Rocky Mountain House, Drayton Valley and Devon) were summed up and converted to a load/day from the load/month values that were shown above in Tables 4.8 to 4.11, and are shown below as "TM*" in Table 4.16. The average daily load as load/day totaled for all three WWTP upstream of the City of Edmonton are shown as the "TAD*" value below in Table 4.16.

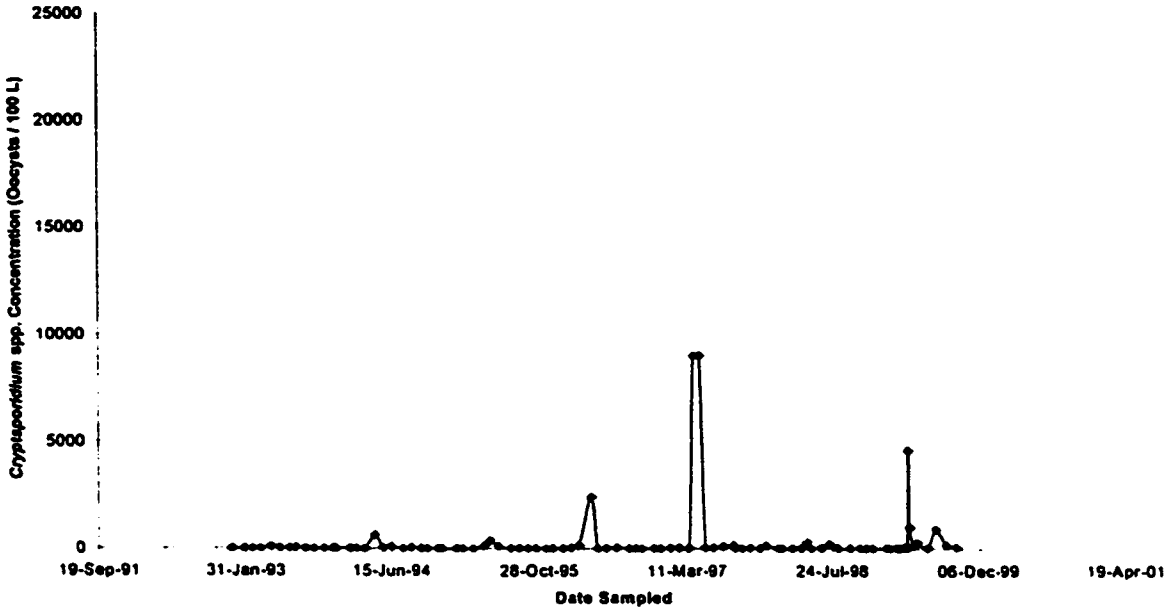

Figure 4.24 North Saskatchewan River *Cryptosporidium* spp. Concentrations Measured at the EL Smith Water Treatment Plant (1992-1999)

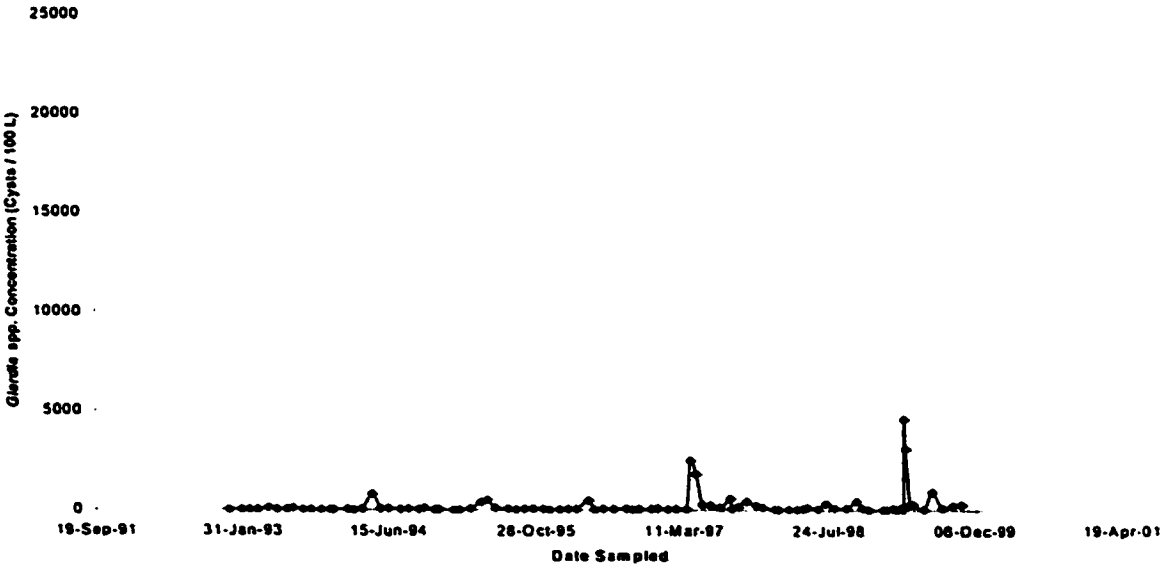

Figure 4.25 North Saskatchewan River *Giardia* spp. Concentrations Measured at the EL Smith Water Treatment Plant (1992-1999)

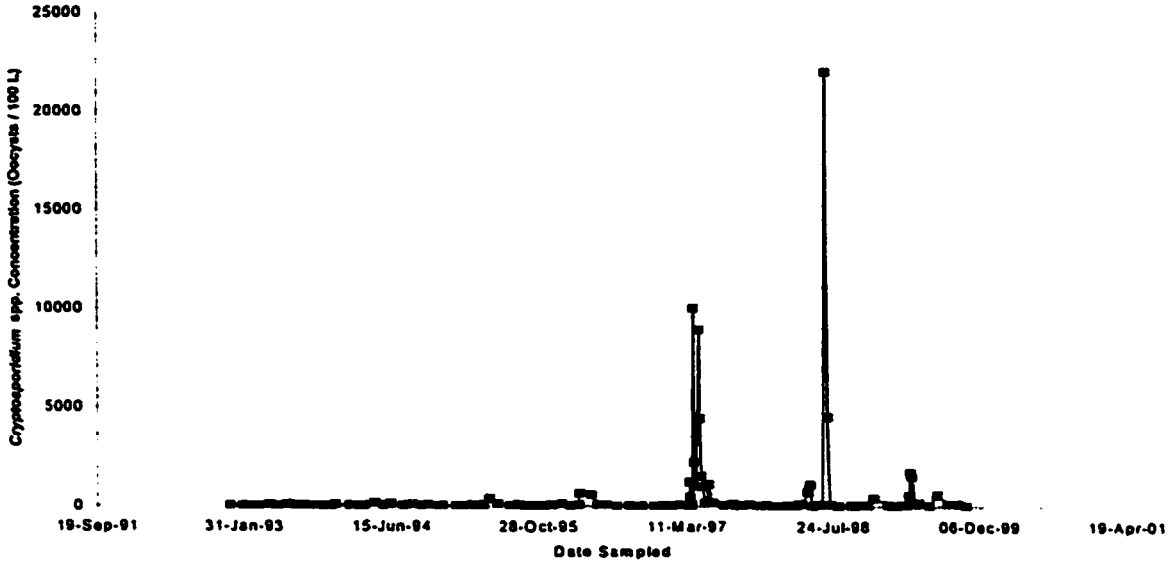

Figure 4.26 North Saskatchewan River *Cryptosporidium* spp. Concentrations Measured at the Rossdale Water Treatment Plant (1992-1999)

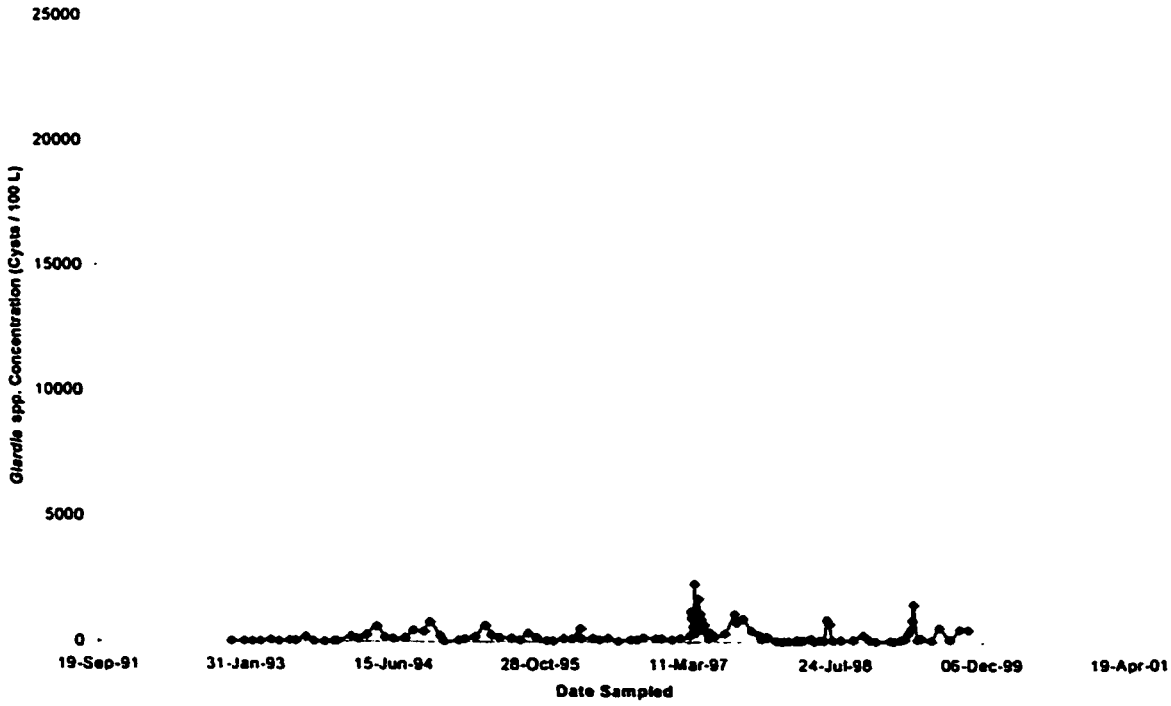

Figure 4.27 North Saskatchewan River *Giardia* spp. Concentrations Measured at the Rossdale Water Treatment Plant (1992-1999)

Table 4.16 Wastewater Treatment Plants in North Saskatchewan Basin, Upstream of the City of Edmonton *Cryptosporidium* spp. and *Giardia* spp. Loading Estimates, 1999 (Load/Day)

Cryptosporidium spp.

	January	February	March	April	May	June	July	August	September	October	November	December
RMH*	2.73E+09	1.66E+09	1.23E+09	1.51E+09	1.49E+09	1.68E+09	2.34E+09	1.97E+09	1.81E+09	7.70E+08	3.70E+08	3.26E+08
DV*	6.05E+08	3.00E+08	2.35E+08	4.94E+08	7.66E+08	2.28E+08	8.88E+07	2.65E+08	6.28E+08	8.24E+08	1.68E+09	1.31E+09
Devon*	4.91E+08	4.50E+08	1.47E+08	2.14E+08	3.60E+08	2.39E+08	1.95E+08	4.79E+08	1.26E+09	2.39E+08	4.56E+07	4.63E+07
TM*	3.83E+09	2.41E+09	1.61E+09	2.22E+09	2.61E+09	2.15E+09	2.62E+09	2.71E+09	3.69E+09	1.83E+09	2.10E+09	1.68E+09
TAD+	1.24E+08	8.30E+07	5.20E+07	7.39E+07	8.43E+07	7.16E+07	8.46E+07	8.74E+07	1.23E+08	5.91E+07	6.98E+07	5.41E+07

Giardia spp.

	January	February	March	April	May	June	July	August	September	October	November	December
RMH*	3.72E+10	2.94E+10	3.66E+10	6.18E+09	7.66E+08	3.22E+08	1.78E+08	6.54E+08	3.82E+09	5.01E+09	2.52E+10	1.96E+10
DV*	3.72E+10	2.94E+10	3.66E+10	6.18E+09	7.66E+08	3.22E+08	1.78E+08	6.54E+08	3.82E+09	5.01E+09	2.52E+10	1.96E+10
Devon*	4.91E+10	4.50E+10	3.81E+10	3.52E+10	3.74E+10	1.40E+10	6.39E+09	7.58E+09	9.58E+09	1.19E+10	1.48E+10	1.50E+10
TM*	1.23E+11	1.04E+11	1.11E+11	4.76E+10	3.90E+10	1.46E+10	6.74E+09	8.89E+09	1.72E+10	2.19E+10	6.52E+10	5.42E+10
TAD+	3.98E+09	3.58E+09	3.59E+09	1.59E+09	1.26E+09	4.88E+08	2.18E+08	2.87E+08	5.74E+08	7.08E+08	2.17E+09	1.75E+09

*loading values in load/month for the sum of all three WTPs

+loading value in load/day for the sum of all three WTPs (Total Monthly/number of days in month)

RMH = Rocky Mountain House

DV = Drayton Valley

TM = Total Monthly Effluent Loading for all three WWTPs upstream of Edmonton

TAD = Total Average Daily Effluent Loading for all three WWTPs upstream of Edmonton

The 1999 loadings for the STL upstream of Edmonton (Table 4.12) were also converted to loads/day (Table 4.17). The protozoan concentration values along with the instantaneous flow values for the comparative sub-watershed study were also converted to load/day values (Tables 4.18 and 4.19).

Table 4.17: Sewage Treatment Lagoons *Cryptosporidium* spp. and *Giardia* spp. Loading Estimates in the North Saskatchewan River Basin, Upstream of the City of Edmonton, 1999, ((oo)cyst/Day)

Lagoon	Date 1999	*Cryptosporidium* spp. Load (#oocysts/day)	*Giardia* spp. Load (#cysts/day)
Alderflats	Oct. 18-21	5.49E+08	5.49E+08
Breton	Oct. 15-29	2.90E+06	2.90E+06
Buck Creek*	June 15-30	2.19E+07	2.95E+07
Calmar	Aug. 3-16	3.51E+07	3.51E+07
Rocky Rapids	May 4-7	1.59E+08	1.59E+08
Sunnybrook**	Oct. 18-22	2.70E+07	1.02E+07
Thorsby	Oct. 12-19	1.56E+08	7.80E+07
Tomahawk (main)	April 7-8	6.71E+07	3.63E+09
Tomahawk (main)	Nov. 1-4	3.86E+07	1.05E+09
Tomahawk (school)	Nov. 1-2	4.04E+07	1.34E+07
Violet Grove	April 8-12	8.69E+07	1.42E+07
Warburg	April 13- May 4	3.71E+09	6.33E+08
Winfield	Oct. 21-25	4.50E+07	1.80E+08

* Lagoon effluent was not sampled. *Cryptosporidium* spp. and *Giardia* spp. concentrations used to calculate load were estimated by taking the geometric mean of similar sized lagoons, based on 1999 data

** Lagoon effluent not sampled in 1999. Lagoon flow and concentrations based on 1998 sample data

The loading values at the EL Smith WTP were converted to loads/day for both *Cryptosporidium* spp. and *Giardia* spp. (Appendix K). These estimated loads are shown in Figures 4.28, 4.29, 4.32 and 4.33 together with the estimated loadings from the three WWTPs upstream of the City of Edmonton, the STLs, and the comparative sub-watershed creeks studied in 1999.

Table 4.18 Comparative Sub-watersheds *Cryptosporidium* spp. Loading Estimates in the North Saskatchewan River Basin, Upstream of the City of Edmonton, 1999 (Oocysts/Day)

	Tomahawk Creek # oocysts/d	Mishow Creek # oocysts/d	Weed Creek # oocysts/d	Strawberry Creek # oocysts/d	Nordegg River # oocysts/d	Baptiste River # oocysts/d	Sum of Measured Creek Load # oocysts/d
2-Apr-99	2.60E+07						2.60E+07
3-Apr-99			3.89E+10				3.89E+10
7-Apr-99		2.2E+08					2.20E+08
8-Apr-99	6.92E+07		1.19E+11				1.19E+11
9-Apr-99				9.12E+10			9.12E+10
10-Apr-99		1.51E+10					1.51E+10
11-Apr-99			7.02E+10				7.02E+10
12-Apr-99	2.86E+10						2.86E+10
13-Apr-99		1.16E+11		6.10E+11			7.25E+11
14-Apr-99			2.04E+10				2.04E+10
15-Apr-99	3.40E+10						3.40E+10
16-Apr-99		3.47E+10		1.41E+10	5.61E+08	3.992E+09	5.34E+10
18-Apr-99	2.20E+10						2.20E+10
19-Apr-99		7.49E+09					7.49E+09
20-Apr-99			2.57E+08	2.87E+09			3.13E+09
21-Apr-99	1.07E+09						1.07E+09
22-Apr-99		9.47E+08			3.54E+09	6.24E+09	1.07E+10
23-Apr-99	2.75E+08			1.12E+09			1.40E+09
26-Apr-99		2.17E+08					2.17E+08
27-Apr-99			7.44E+07		2.90E+09	2.659E+09	5.64E+09
28-Apr-99	8.94E+08			3.64E+08			1.26E+09
30-Apr-99					1.88E+08	7.65E+08	9.53E+08
3-May-99		1.46E+10			1.64E+08	5.12E+08	1.53E+10
4-May-99			1.81E+08				1.81E+08

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	Tomahawk Creek # oocysts/d	Mishow Creek # oocysts/d	Weed Creek # oocysts/d	Strawberry Creek # oocysts/d	Nordegg River # oocysts/d	Baptiste River # oocysts/d	Sum of Measured Creek Load # oocysts/d
5-May-99	1.34E+09						1.34E+09
6-May-99				5.98E+08			5.98E+08
10-May-99		1.06E+08			2.27E+08	7.76E+07	4.11E+08
11-May-99			4.00E+06				4.00E+06
12-May-99	4.42E+07						4.42E+07
13-May-99				2.68E+07			2.68E+07
22-Jun-99		5.81E+05					5.81E+05
23-Jun-99	1.11E+07			2.90E+07			4.01E+07
24-Jun-99			1.47E+06				1.47E+06
29-Jun-99					9.95E+08	1.076E+09	2.07E+09
8-Jul-99	6.20E+09	1.13E+09	1.82E+07	2.13E+09			9.49E+09
9-Jul-99	1.03E+09	1.16E+08	1.08E+10	6.35E+10	1.55E+10	5.225E+11	6.13E+11
10-Jul-99	1.73E+09		1.84E+09	1.32E+10			1.67E+10
12-Jul-99					3.38E+09	1.617E+10	1.96E+10
13-Jul-99	8.58E+07		3.67E+06	3.12E+08			4.01E+08
15-Jul-99				3.28E+08	9.44E+11	1.398E+12	2.34E+12

Table 4.19 Comparative Sub-watersheds *Giardia* spp. Loading Estimates in the North Saskatchewan River Basin, Upstream of the City of Edmonton, 1999 (Cysts/Day)

Date Sampled	Tomahawk Creek # cysts/d	Mishow Creek # cysts/d	Weed Creek # cysts/d	Strawberry Creek # cysts/d	Nordegg River # cysts/d	Baptiste River # cysts/d	Sum of Measured Creek Load # cysts/d
2-Apr-99	5.42E+07						5.42E+07
3-Apr-99			1.92E+09				1.92E+09
7-Apr-99		1.76E+09					1.76E+09
8-Apr-99	2.10E+08		3.01E+11				3.01E+11
9-Apr-99				1.37E+12			1.37E+12
10-Apr-99		7.74E+09					7.74E+09
11-Apr-99			1.81E+10				1.81E+10
12-Apr-99	2.16E+10						2.16E+10
13-Apr-99		5.85E+10		6.10E+11			6.68E+11
14-Apr-99			5.09E+09				5.09E+09
15-Apr-99	3.40E+10						3.40E+10
16-Apr-99		3.47E+10		1.41E+10	1.65E+08	2.18E+09	5.12E+10
18-Apr-99	2.20E+10						2.20E+10
19-Apr-99		3.61E+09					3.61E+09
20-Apr-99			1.29E+08	2.87E+09			3.00E+09
21-Apr-99	1.07E+09						1.07E+09
22-Apr-99		9.47E+08			3.54E+09	1.90E+10	2.35E+10
23-Apr-99	2.75E+08			5.73E+09			6.00E+09
26-Apr-99		4.29E+08					4.29E+08
27-Apr-99			2.60E+08		9.68E+08	2.66E+09	3.89E+09
30-Apr-99					1.88E+08	3.82E+09	4.01E+09

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Date Sampled	Tomahawk Creek # cysts/d	Mishow Creek # cysts/d	Weed Creek # cysts/d	Strawberry Creek # cysts/d	Nordegg River # cysts/d	Baptiste River # cysts/d	Sum of Measured Creek Load # cysts/d
30-Apr-99					1.88E+08	3.82E+09	4.01E+09
3-May-99		1.46E+10			4.93E+08	5.12E+08	1.56E+10
4-May-99			5.62E+08				5.62E+08
5-May-99	1.34E+09						1.34E+09
6-May-99				3.07E+09			3.07E+09
11-May-99			8.34E+06				8.34E+06
12-May-99	4.42E+07						4.42E+07
13-May-99				5.18E+07			5.18E+07
22-Jun-99		1.45E+07					1.45E+07
23-Jun-99	1.10E+07						1.10E+07
29-Jun-99					9.95E+08	3.23E+09	4.22E+09
8-Jul-99	6.20E+09	1.13E+10	3.65E+07	2.13E+09			1.97E+10
9-Jul-99	1.03E+09	1.16E+08	1.08E+10	6.35E+10	1.55E+10	1.26E+11	2.17E+11
10-Jul-99	3.07E+09		1.47E+09	2.63E+10			3.09E+10
12-Jul-99					3.38E+09	4.85E+10	5.19E+10
13-Jul-99	3.47E+08		7.34E+06	6.23E+08			9.77E+08
15-Jul-99				6.47E+08	9.44E+11	4.73E+11	1.42E+12

It is recognized that in totaling the estimated loadings and not taking into account a decay factor, or die-off rate a worst case estimate of the loadings that the WWTPs, STLs and the comparative sub-watershed creeks can contribute to the loads observed at the EL Smith WTP will result. It should be noted that the Gold Bar WWTP is located downstream of both the E.L. Smith and Rossdale WTP and therefore its estimated loadings were not added into the mass loading calculations. Figures 4.28, and 4.29, show the *Cryptosporidium* spp. loading values observed at the EL Smith WTP and the estimated loads resulting from the WWTPs, STLs and the comparative sub-watershed creeks. It should be noted that the loads calculated are estimated loads, and as such have an error associated with them. There are limitations in both the sample collection method, and the sample processing and analysis method used to obtain the concentrations of *Cryptosporidium* spp. and *Giardia* spp. As well, the instantaneous flows were used to calculate the loadings, and a much stronger estimate would result from using the daily flow values from a hydrograph for each creek. The sewage lagoons were only sampled once during their discharge, and that one sample was assumed representative of the concentrations of *Cryptosporidium* spp. and *Giardia* spp. over the entire discharge period. The WWTPs were only sampled every other month, and estimates of the months not sampled were calculated based on geometric means.

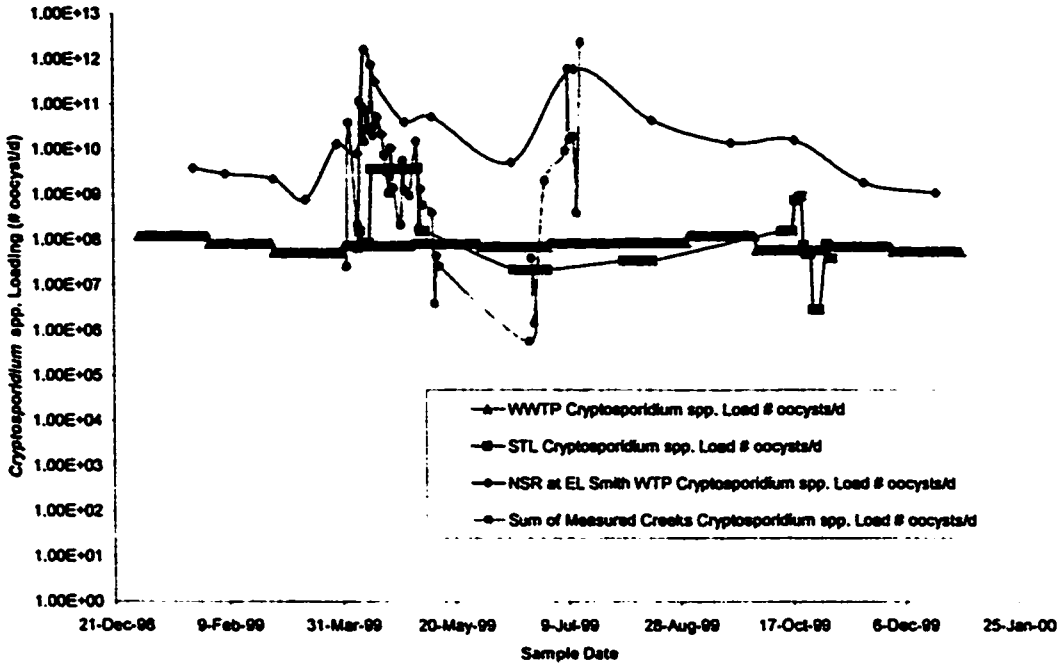


Figure 4.28: EL Smith WTP Source Water, Wastewater Treatment Plants and Sewage Treatment Lagoons Upstream of Edmonton, and Comparative Sub-Watershed (6 Creeks) *Cryptosporidium* spp. Loading, 1999

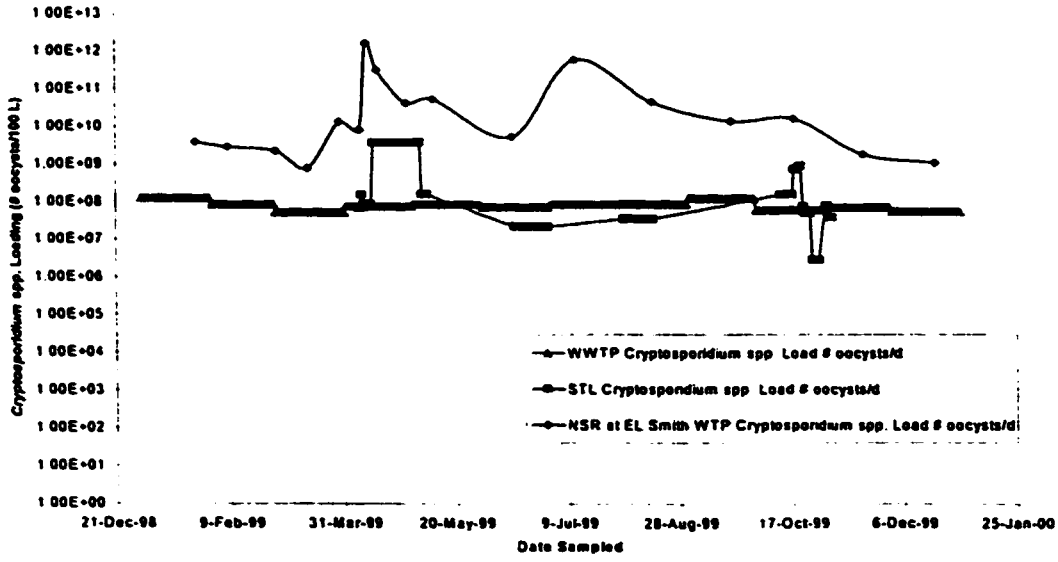


Figure 4.29: EL Smith WTP Source Water, and Wastewater Treatment Plants Upstream of Edmonton *Cryptosporidium* spp. Loading, 1999

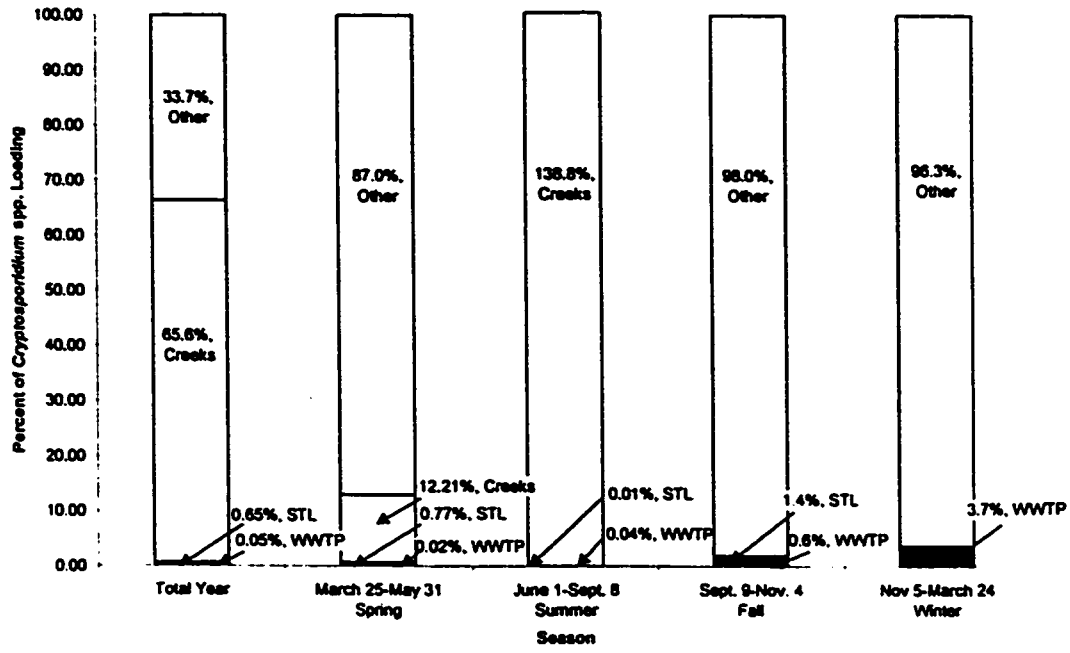


Figure 4.30: Percentages of *Cryptosporidium* spp. Loading Observed at EL Smith WTP, 1999

Figure 4.30 shows the percentages of *Cryptosporidium* spp. loading at EL Smith for the total year, spring, summer, fall and winter. The seasons were defined based on the hydrograph for flows in the NSR at Edmonton for 1999. The hydrograph is shown in Figure 4.31. From the hydrograph, spring was defined as the period from March 25 to May 31, summer was defined as the period from June 1 to September 8, fall was defined as the period from September 9 to November 4, and winter was defined as the period from November 5 to March 24, for the year 1999. The "other" value shown in Figures 4.30 and 4.34 represents the unaccounted percentage of loadings observed at EL Smith WTP. It is hypothesized that this value is largely made up of the loadings from all other tributaries flowing into the NSR other than the six measured creeks in the

comparative sub-watershed study. The value of 138.8% for the *Cryptosporidium* spp. loading from the measured creeks during the summer of 1999 is a result of a load from a wildlife sub-watershed site, sampled in July y, being higher than the load observed at the EL Smith WTP on that same day. Therefore this sample made up over 100 % of the load observed at EL Smith on that day.

The WWTPs and STLs do not account for a large percentage of the *Cryptosporidium* spp. loadings observed at the EL Smith WTP. There is a slight impact from WWTPs during the winter months. There were no STLs that discharged past November 4th in 1999, and as such, there is no contribution from STLs over the winter period. As well, there were no creek samples taken past the end of July in 1999, and as such, there were no contributions in the fall or winter months from the creeks considered. Even with having creek samples for only a small percentage of the creeks that flow into the NSR (only 6 creeks), the contribution from these sources makes up over 65% of the total yearly average *Cryptosporidium* spp. loading observed at the EL Smith WTP. During the summer period, the creeks account for over 100% of the average *Cryptosporidium* spp. load observed at the EL Smith WTP. This high percentage is a result of the one creek sample that had a *Cryptosporidium* spp. concentration value higher than observed at the EL Smith WTP on the same day. Figure 4.29 shows that there is a consistent, baseline *Cryptosporidium* spp. load to the NSR from the WWTPs, and the STLs in the basin. The STLs have substantial loads in the spring time, and late fall.

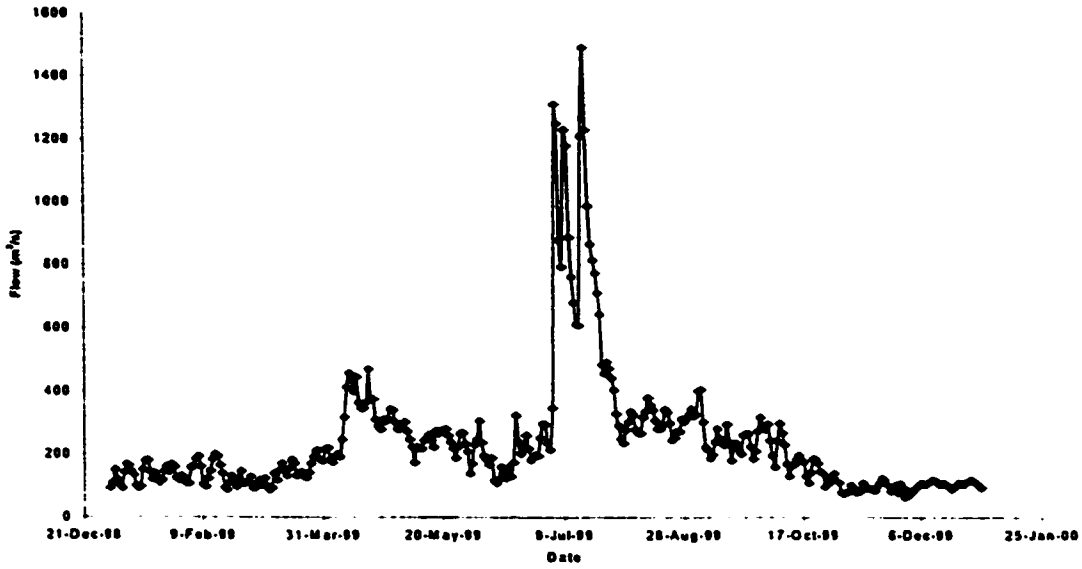


Figure 4.31 1999 Hydrograph for Flows in the North Saskatchewan River Basin, at Edmonton

Figures 4.32 and 4.33 show the *Giardia* spp. loading values observed at the EL Smith WTP and the contributions that the WWTP, STLs and the 6 creeks sampled during the comparative sub-watershed study account for. Figure 4.34 shows the percentages of *Giardia* spp. loading at EL Smith for the total year, and for the spring, summer, fall, and winter seasons.

The WWTPs account for over 22% of the average loading observed at the EL Smith WTP during the winter months of 1999. As with *Cryptosporidium* spp., there were not STL or creek samples taken during the winter months. The creeks, and WWTPs make up more of the average *Giardia* spp. load observed at the EL Smith WTP over spring than the do for the *Cryptosporidium* spp. load over spring in 1999. The creeks make up over 83% of the average *Giardia* spp. load

observed at the EL Smith WTP over the summer in 1999, where as the WTPs and STLs load are similar in the spring and summer periods of 1999. Over the total year, the creeks account for over 51% of the average *Giardia* spp. load observed at the EL Smith plant in 1999.

Figure 4.33 shows that there is a constant baseline *Giardia* spp. load to the NSR from the WTPs. However, there is a decline in the *Giardia* spp. load during the late spring and the summer, with the load increasing in late fall. This decrease is not observed for the *Cryptosporidium* spp. load from the WWTPs. As well, the *Giardia* spp. loadings from the STLs are substantially lower than the

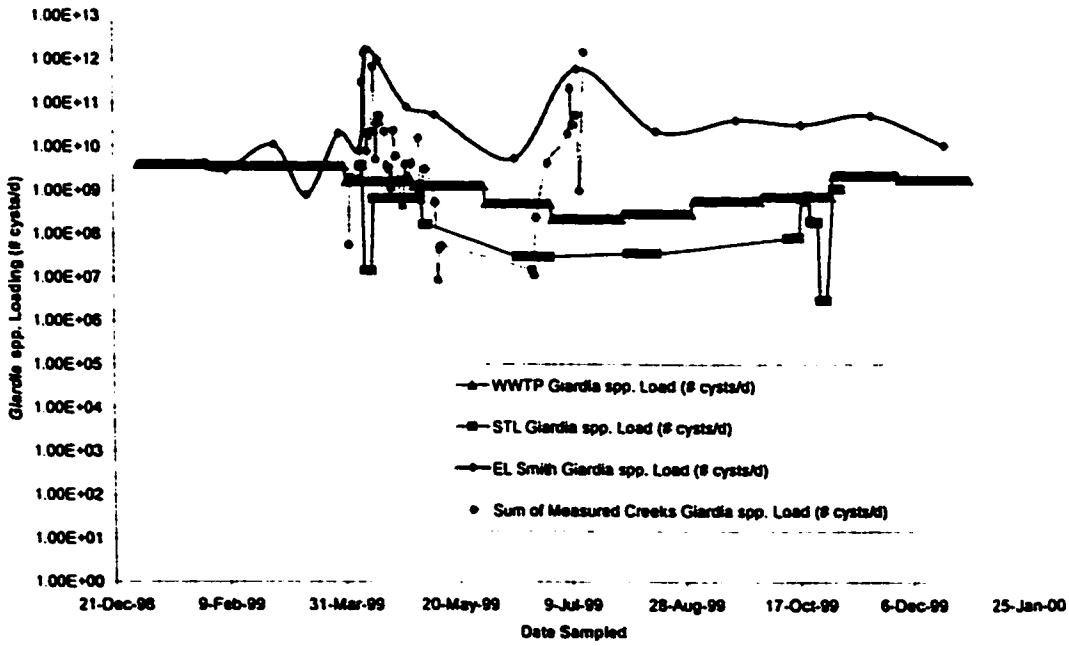


Figure 4.32: EL Smith WTP Source Water, Wastewater Treatment Plants and Sewage Treatment Lagoons Upstream of Edmonton, and Comparative Watershed (6) Creeks *Giardia* spp. Loading, 1999

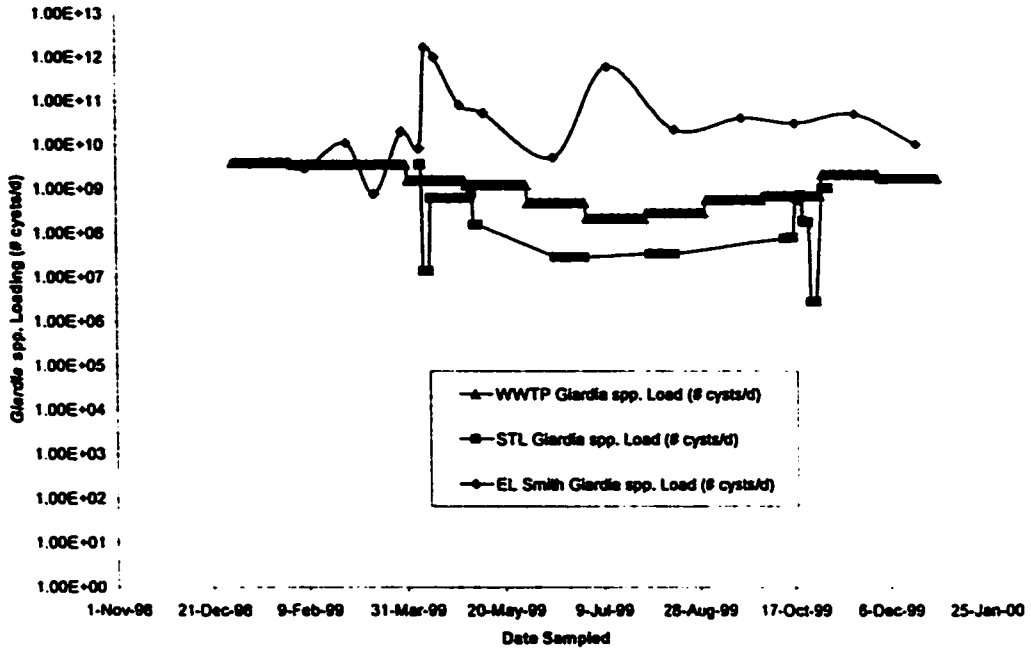


Figure 4.33: EL Smith WTP Source Water, Wastewater Treatment Plants and Sewage Treatment Lagoons Upstream of Edmonton *Giardia* spp. Loading, 1999

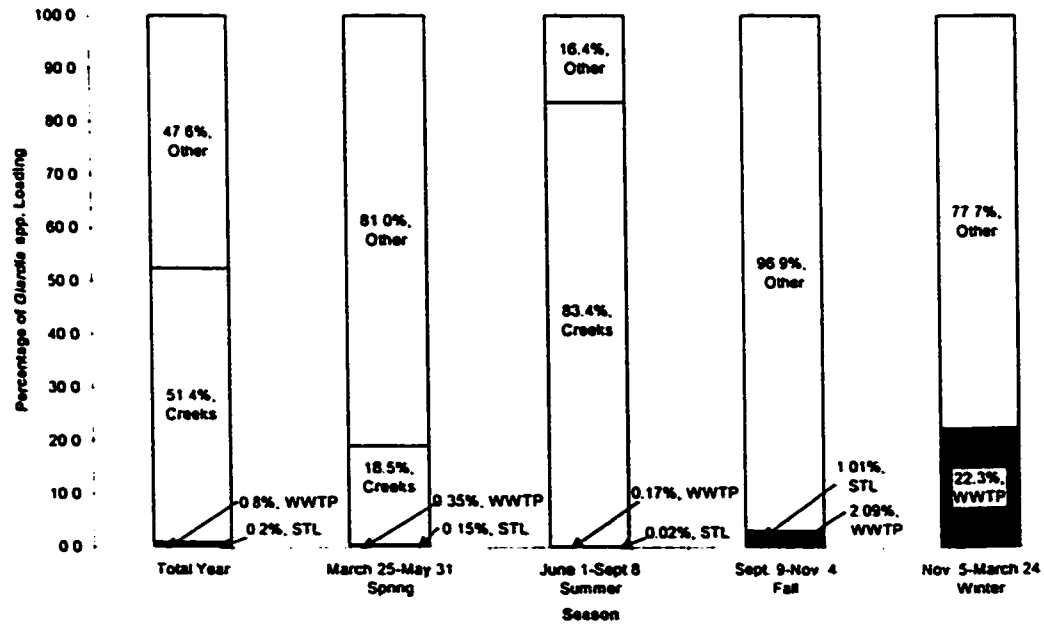


Figure 4.34: Percentages of *Giardia* spp. Loading Observed at EL Smith WTP, 1999

Cryptosporidium spp. loads that the STLs contribute to the NSR.

Since the creeks were substantial contributors of the *Cryptosporidium* spp. and *Giardia* spp. loadings observed at the EL Smith WTP, the contributions from the creeks were calculated based on the sub-watershed classification that the creek represented; wildlife, high beef cattle, and high agriculture. Figures 4.35 and 4.36 show the percent contribution of *Cryptosporidium* spp. and *Giardia* spp. loading, respectively, based on sub-watershed classification.

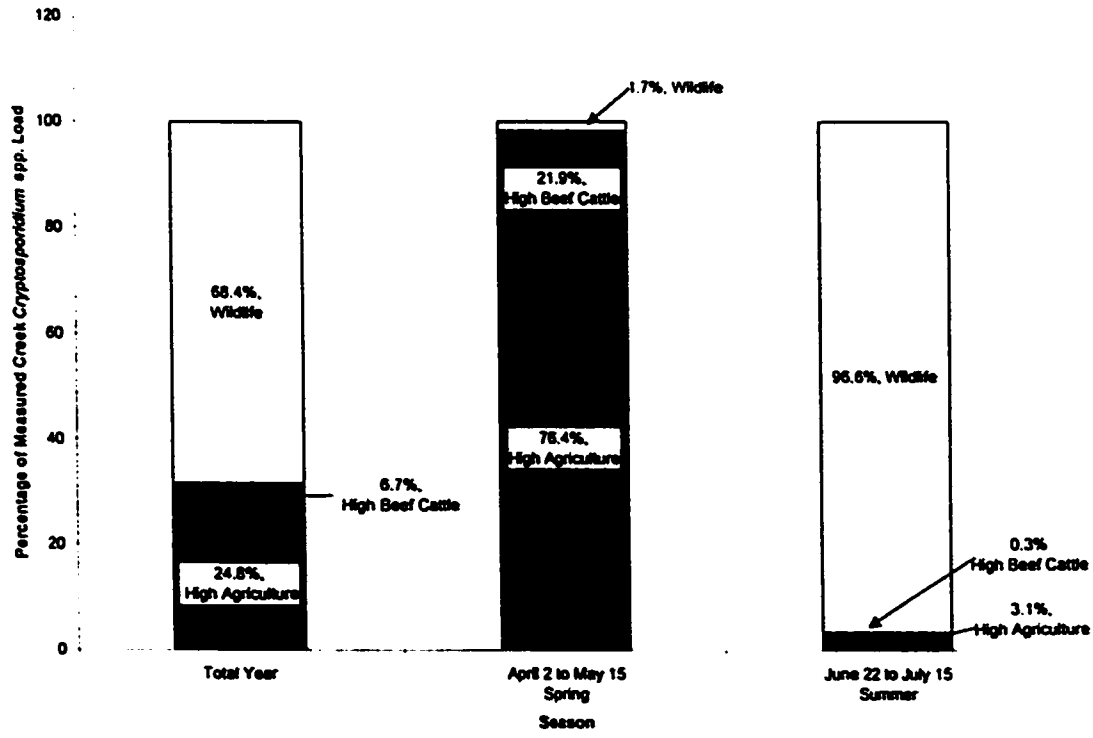


Figure 4.35: Percent Distribution of *Cryptosporidium* spp. Loading from Classified Creek Types, 1999

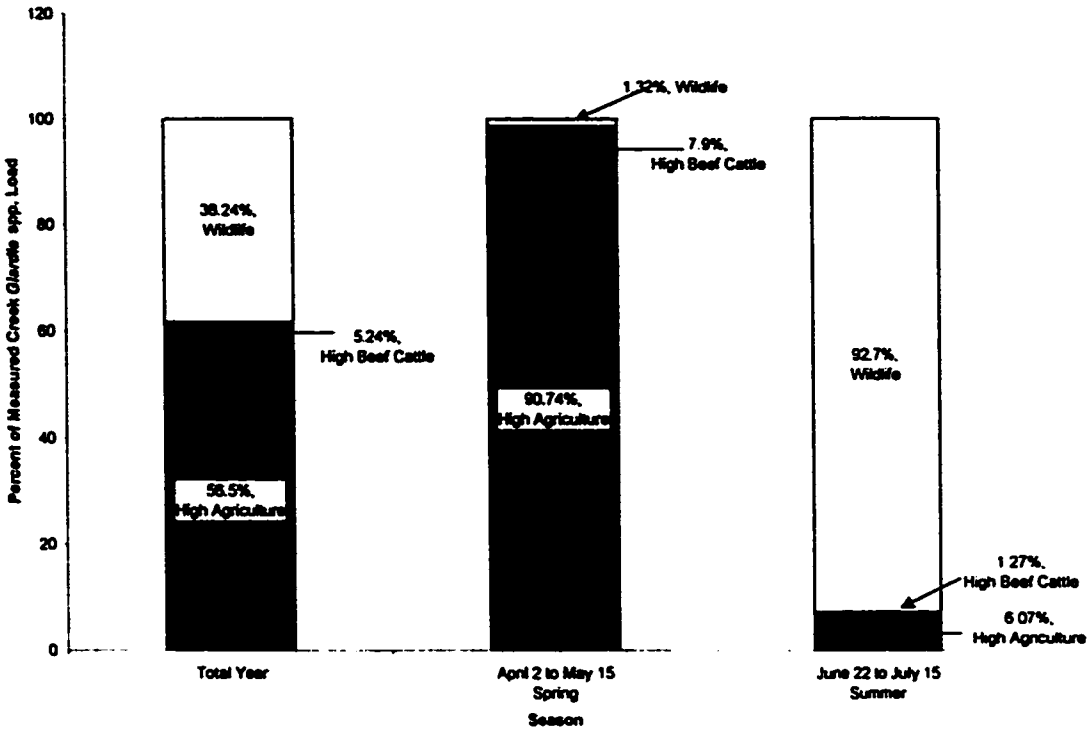


Figure 4.36: Percent Distribution of *Giardia* spp. Loading from Classified Creek Types, 1999

The wildlife sub-watersheds were the most substantial contributors of *Cryptosporidium* spp. and *Giardia* spp. in the summer months, accounting for over 96% and 92% of the total creek *Cryptosporidium* spp. and *Giardia* spp. loading, respectively. As well, their impact was significant over the total year of creek data (April 2-July 15) in 1999, with the wildlife creeks accounting for over 68% and 38% of the total creek *Cryptosporidium* spp. and *Giardia* spp. loading, respectively. Both wildlife creeks contributed the largest loadings of *Cryptosporidium* spp. and *Giardia* spp. in the late summer, July 12-15th, 1999. It was at this time that there was a significant rainstorm event in the basin, as shown in the NSR basin hydrograph (Figure 4.31). These high loadings during

the summer storm would indicate that summer rainstorm events are an apparent factor in the transport of *Cryptosporidium* spp. and *Giardia* spp. to the river, and through, the basin.

A thorough investigation of the Baptiste River watershed resulted in determining that there is an Indian Reservation just upstream of the mouth sampling station. The Reservation may have a sewage effluent discharge, which may have increased the *Cryptosporidium* spp. and *Giardia* spp. loadings. As well, both the Nordegg and Baptiste Rivers are favorite locations for summer campers, with a substantial number of campgrounds established along their banks. Again, this increase in activity during summer months may have lead to an increase in the presence of *Cryptosporidium* spp. and *Giardia* spp. in these "pristine" wildlife sub-watersheds. As well, the significance of the wildlife located west of Rocky Mountain House may have been underestimated, and it may in fact be a substantial source of both *Cryptosporidium* spp. and *Giardia* spp. in the NSR basin.

The high agriculture sub-watersheds account for over 76% and 90% of the total creek *Cryptosporidium* spp. and *Giardia* spp. loadings, respectively, during the spring season (April 2-May 15 for creek samples). The high beef cattle sub-watersheds accounted for over 21% and 7% of the *Cryptosporidium* spp. and *Giardia* spp. loadings, respectively, during the spring season.

Over the total year, the high agriculture sub-watersheds contributed over 24% and 56% of the total creek *Cryptosporidium* spp. and *Giardia* spp. loading, respectively. The high beef cattle sub-watersheds contributed over 6% and 5% of the total creek *Cryptosporidium* spp. and *Giardia* spp. loadings, respectively.

5.0 CONCLUSIONS

The loading values calculated for the EL Smith WTP protozoan loading analysis were based only on 1999 measured values. The protozoan loads calculated at the EL Smith WTP were based on measured concentrations in the NSR at Edmonton, and continuously flow data provided by Environment Canada. For the concentration values found to be below the detection limit (17.6% [6/34]), the detection limit value was used for the calculation of the load. The protozoan loading values calculated for the six creeks measured for the comparative sub-watershed study were based on measured concentrations and instantaneous flow values measured in the field at the time of sampling. For concentrations found to be below the detection limit (32.1% [50/156]) the detection limit value was used in the calculation of a load. The protozoan loading values calculated for the WWTP were based on the measured concentrations and the total monthly effluent flow values provided by the WWTP operators and reported to Alberta Environment. For concentrations found to be below the detection limit (21.8% [17/78]), the detection limit value was used in the calculation of a load. For the months that concentrations were not sampled, the geometric mean of the month immediately before and after was calculated and used in the calculation of the load. The protozoan loading values calculated for the STLs were based on measured concentrations and total volume of effluent discharged. For the concentration values found to be below the detection limit (25.0% [8/32]), the detection limit value was used in the calculation of the load. The protozoan loading values used for the Sunnybrook STL were values measured in 1998.

The Buck Creek STL was not sampled in 1999, and the concentrations of protozoan were estimated by calculating the geometric mean of all other lagoons sampled in 1999. The total effluent discharged in 1999 by Buck Creek STL was the actual value in 1999.

Cryptosporidium spp. and *Giardia* spp. are present in the NSR basin. The watershed studied is not unique or unusual in its water quality. This watershed exhibits a range of watershed conditions and activities that are representative of many of those in Western Canada. Therefore, the presence of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in each of the river water samples suggests a broad geographical distribution and continuous presence of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in surface waters (Ongerth 1987).

The presence of *Giardia* spp. during the winter months can be explained partially as a point source load from wastewater treatment facilities in the basin upstream of Edmonton. The small percentage of creeks that were studied intensely (6 creeks) had a substantial contribution to *Giardia* spp. during summer (83.4%), and over the total year (51.4%). The small percentage of creeks also accounted for over 18% of the *Giardia* spp. load during spring runoff

The wastewater treatment plants and sewage treatment lagoons accounted for a very small percentage of the loadings of *Cryptosporidium* spp. observed in the NSR basin. The STLs accounted for 0.65%, 0.77%, 0.01% and 1.4% of the *Cryptosporidium* spp. loadings observed at the EL Smith WTP over the total

year, spring, summer and fall, respectively. The WWTPs accounted for 0.05%, 0.02%, 0.04%, 0.6%, and 3.7% of the *Cryptosporidium* spp. loadings observed at the EL Smith WTP over the total year, spring, summer, fall, and winter, respectively. The small percentage of creeks studied intensely (6 creeks) accounted for 65.6%, 12.21%, and 138.8%, of the *Cryptosporidium* spp. loadings observed at the EL Smith plant over the total year, spring, and summer, respectively. The large percentages that the six measured creeks account for indicate that *Cryptosporidium* spp. is to a large extent a result of nonpoint sources. Nonpoint sources are more difficult to account for and manage in a basin. The loading is explained by the contribution of diffuse sources, and may be cumulative loading issue. For example, one creek's loading accounts for a small percentage, however, if the loadings from all creeks are accumulated, the effect can be substantial. Due to the fate mechanisms of *Cryptosporidium* spp., the increased presence of the protozoan is observed during intense flow events, such as spring runoff, or summer rainstorm events.

The presence of *Giardia* spp. cysts in the winter is more of a risk than in the summer. The water utilities find it more difficult to effectively inactivate the cysts during the cold winter months (Gammie 2000). Gammie (2000) has observed that the cysts are easier to inactivate during the summer months, and therefore the real risk may be the consistent load observed from the WWTPs in the basin during the winter months. EPCOR is presently spending in the millions of dollars to upgrade its water treatment plants to move from 3-log to 5-log *Giardia* spp.

reduction capabilities. The smaller WTPs upstream of Edmonton in the NSR basin are at the similar risk of *Giardia* spp. in their source water, however, they are not in the position to spend this sum of money to move to 5-log reduction in *Giardia* spp.. Their best option is to identify the sources of both *Cryptosporidium* spp. and *Giardia* spp. in the basin, and then reduce their loadings into the basin.

As discussed in section 3.1.1.3, the upstream/downstream sampling sites were chosen based on the willingness of the cooperators to participate in the study. As well, they had sampling locations that were feasible for monitoring and accessible, but mostly, the operation promoted runoff and drainage from the far to the creek flowing through the operation. The samples taken immediately upstream and downstream of an operation were not substantially different. These findings are similar to those of Sischo et al. (2000), who found that when they were able to obtain upstream/downstream samples, the downstream sample had lower prevalence (2%) than the upstream samples (8%) for *Cryptosporidium* spp. Based on the results of the upstream/downstream sampling study, not conclusions can be drawn. However, the results combined with the sampling performed at the mouth of the creeks as part of the comparative sub-watershed study suggest that he contribution of protozoan is a result of cumulative impacts along the creek. The cooperator farms where upstream/downstream sampling was conducted were not randomly selected, rather they were chosen based on willingness of cooperators to participate in the study. The cooperators who were willing to participate in this study may in fact be those operators in the basin who

conduct best management practices. If other farms were studied upstream/downstream, the results may not be the same, and in fact there may be substantial differences between the concentrations prior to and immediately after the contributing operation. It is hypothesized that poorly managed farms would have a larger impact and an apparent difference in the upstream/downstream concentrations would be noticed. The concentrations and loads observed at the mouth of each stream was substantially higher levels than those observed upstream in the sub-watersheds. The concentrations of cumulative operations within a sub-watershed were substantial, and this was consistent with the view (Ongerth 1987; Buret 1990; Ong 1996) that infected livestock may contribute to parasite contamination.

Cryptosporidium spp. and *Giardia* spp. are a problem for the farmers themselves, who, together with their stock, are prone to cryptosporidiosis and giardiasis. The diseases can cause a decrease in production, and associated decrease in economic benefits when stock become infected. For these reasons it is in the best interest of producers and cooperators to practice good management strategies, which may include restricting access of calves to creeks during their first four months. By restricting calves from low ground, where their feces may be easily washed into creeks, the contamination of surface waters will be substantially decreased. As well, Sischo et al. (2000) showed that the single highest risk factor for detecting *Cryptosporidium* spp. in surface water was the frequency of spreading manure on fields. The practice of spreading manure on

frozen ground causes an even more severe impact during spring runoff. Good watershed management practices, to limit cumulative loading effects, are clearly important to the provision of the best-quality surface drinking water supplies.

There are a number of factors, that acting together, contribute to the presence of *Cryptosporidium* spp. and *Giardia* spp. in the basin. The cumulative effects of spreading manure on frozen ground, spring runoff, the timing of spring runoff, as well as the timing of STL discharges and the continuous presence of WWTP effluent increase the risk of the occurrence of the waterborne diseases caused by the presence of these protozoa.

This study was the first of its kind in Canada to determine the relative concentrations and estimated loadings of *Cryptosporidium* spp. and *Giardia* spp. for all possible sources in a large watershed (over 27 000 km^2). The baseline data obtained from this research will provide much needed background information on the relative concentrations and loadings that wildlife, agriculture and municipal sewage effluents contribute to raw source water. The work constituted one component of a multi-agency, multi-partner study monitoring waterborne parasites in source waters of the NSR basin. This project is an example of a successful cooperative effort of all stakeholders in the basin. The work would not have been possible without the cooperation of landowners; and, municipal, provincial and federal government agencies. The sheer volume of samples collected and processed have contributed to the general knowledge of

concentrations and loadings of *Cryptosporidium* spp. and *Giardia* spp. in a large watershed.

6.0 RECOMMENDATIONS

1. A more reliable sampling and processing method are needed to accurately measure the concentrations of *Cryptosporidium* spp. and *Giardia* spp. in surface waters. A substantial amount of samples were taken at times when turbidity exceeded the ICR method's (1995) recommended limit of 150 NTU. In the NSR basin, the peak concentrations of these protozoa are observed during spring runoff and summer rainstorm events, during which turbidities are high, and generally exceed 150 NTU. It is difficult to determine, with certainty, the exact percentages each source is contributing to the presence of these protozoa with sampling methods that have a low reliability.

2. An effort should be made to have wastewater treatment facilities in the NSR basin (Rocky Mountain House, Drayton Valley, Devon and Gold Bar) reduce their *Cryptosporidium* spp. and *Giardia* spp. concentrations in their effluent, particularly during winter months, when the risk of (oo)cyst survival is much greater than during the summer months.

3 The Warburg STL lagoon should be operated according to the standards (Alberta Environmental Protection, 1997), and discharge in the fall on a yearly basis. The Tomahawk (main) STL should be upgraded enabling 365 day storage. As well, the Tomahawk (main) STL should discharge during the fall on a yearly basis. An investigation as to why the Winfield STL had high fecal

coliform and *Escherichia coli* concentrations during their fall discharge should be undertaken.

4 The producers in the basin should be educated as to the benefits of good management practices, such as restricting access to the creeks for calves, and manure spreading on frozen ground. The costs of production losses and economics of sickly stock, and the advantages of reducing the presence of *Cryptosporidium* spp. and *Giardia* spp. in the basin should also be passed on to producers.

5 A study to investigate the effect of cumulative agricultural producers on a single creek in the watershed should be conducted. Sampling along a single creek, from the headwaters to the mouth of the confluence with the NSR, during all flow conditions would provide much needed information on the concentration of these protozoa based on agricultural activity in a single sub-watershed. It is hypothesized that there is a saturation level based on the number and or type of agricultural activity within the sub-basin.

6 Further investigation into the contribution of *Cryptosporidium* spp. and *Giardia* spp. concentrations and loadings into the basin based on different farm management practices is warranted. A study investigating manure spreading, barn cleaning practices and biota buffer strips and their varying contributions

to protozoa will yield much need information that can be used for decision making based on management techniques.

7.0 REFERENCES

Adam, R. D. (1991). "The Biology of *Giardia* spp." *Microbiological Review* **55**: 706-732.

Addiss, D. G., M. Arrowood, M. Bartlett, D. Colley, and Juranek, D. D. (1995). "Assessing the Public Health Threat Associated With Waterborne Cryptosporidiosis." Report of a Workshop, MMWR. **44rr-6**: 1-19.

Akin, E. A., and W. Jakubowski (1986). "Drinking Water Transmission of Giardiasis in the United States." *Water Science and Technology* **18**(10): 219-226.

Alberta Environmental Protection. (1997). *Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems*. Standards and Guidelines Branch, Environmental Assessment Division, Environmental Service. Edmonton, Alberta.

American Public Health Association. (1998). *Standard Methods for the Examination of Water and Wastewater, 20th edition*. Washington, DC, American Public Health Association.

Anderson, M. A., M. H. Stewart, M. V. Yates, and C. P. Gerba (1998). "Modeling the Impact of Body-Contact Recreation on Pathogen Concentrations in a Source Drinking Water Reservoir." *Water Research* **32**(11): 3293-3306.

Badenoch, J., C. L. R. Bartlett, C. Benton, D. P. Casemore, R. Cawthorne, F. Earnshaw, K. J. Ives, J. Jeffery, H. V. Smith, M. S. B. Vaile, D. A. Warrell, and A. E. Wright. (1990) "*Cryptosporidium* in Water Supplies." *Report to the Group of Experts*. London.

Belosevic, M., G. M. Faubert, J. D. MacLean, C. Law, and N. A. Croll (1983). "*Giardia* lamblia infections in Mongolian gerbils: an animal model." *Journal of Infectious Disease* **147**: 222-226.

Bingham, A. K., et al. (1979). Induction of *Giardia* Excystation and the Effect of Temperature on Cyst Viability as Compared by Eosin Exclusion and in Vivo Excystation. *Waterborne Transmission of Giardiasis*. W. Jakubowski, and J. C. Hoff. Cincinnati, Ohio, USEPA. **EPA 600/9-79-001**.

Breach, R. A., M. J. Porter, M. L. Furness, D. Dawson, V. W. Howells, and D. W. Black (1994). *An Integrated Water Utility Approach to Minimising the risks Associated with Waterborne Cryptosporidiosis*. American Water Works Association Annual Conference, New York, American Water Works Association

Buret, A., M. denHollander, P. M. Wallis, D. Befus, and M. E. Olson (1990). "Zoonotic Potential of Giardiasis in Domestic Ruminants." *The Journal of Infectious Diseases* **162**: 231-237.

Burkhari, Z., H. V. Smith, N. Sykes, S. W. Humphreys, C. A. Paton, R. W. A. Gridwood, and C. R. Fricker. (1997). "Occurrence of *Cryptosporidium* spp. Oocysts and *Giardia* spp. Cysts in Sewage Influent and Effluent From Treatment Plants in England." *Water Science and Technology*. **35**(11-12): 385-390.

Campbell, I., S. Tzipori, G. Hutchison, and K. W. Angus. (1982). "Effect of Disinfectants on Survival of *Cryptosporidium* Oocysts." *Veterinary Record*. **111**: 414-415.

Casson, L. W., C. A. Sorber, J. L. Sykora, P. D. Gavaghan, M. A. Shapiro, W. Jakubowski (1990). "*Giardia* in Wastewater - Effect of Treatment." *Research Journal - WPCF* **62**(5): 670-675.

Chauret, C., P. Chen, S. Springthorpe, and S. Sattar (1995). *Effect of Environmental Stressors on the Survival of Cryptosporidium oocysts*. AWWA Water Quality Technical Conference, New Orleans, La, American Water Works Association, Denver, Colo.

Chilvers, B. L. (1998). "The Prevalence of Infection of *Giardia* spp. and *Cryptosporidium* spp. in Wild Animals on Farmland, Southeastern North Island, New Zealand." *International Journal of Environmental Health and Research* **8**(1): 59-64.

Clancy, J. L., Z. Bukhari, R. M. McCuin, Z. Matheson, and C. R. Fricker (1999). "USEPA Method 1622." *Journal American Water Works Association* **91**(9): 60-68.

Craun, G. F. (1990). Waterborne giardiasis. *Giardiasis*. E. A. Meyer. New York, NY, Elsevier: 267-293.

Craun, G. F., P. S. Berger, and R. L. Calderon (1997). "Coliform Bacteria and Waterborne Disease Outbreaks." *Journal American Water Works Association* **89**(3): 96-104.

Crockett, C. S., and. C. N. Haas. (1995). "Protozoan Monitoring From the ICR to the ESWTR." *Journal of American Water Works Association*(August): 50 - 59.

Crockett, C. S. a. C. N. H. (1997). "Understanding protozoa in your watershed." *Journal of American Water Works Association* **89**(9): 62 - 73.

Davis, R. B., and C. P. Hibler (1979). Animal Reservoirs and Cross Species Transmission of *Giardia*. *Waterborne Transmission of Giardiasis*. W. Jakubowski,

and J. C. Hoff. Cincinnati, US Environmental Protection Agency. **EPA-600/7-79-01**: 104-126.

de Reginer, D. P., L. Cole, D. G. Schupp, and S. L. Erlandson. (1989). "Viability of *Giardia* Cysts Suspended in Lake, River and Tap Water." *Applied and Environmental Microbiology*. **55**: 1223-1229.

EnSys Inc. Environmental Products (1995). *Hydrofluor-Combo Kit Indirect Immunofluorescent Detection Procedure. For Giardia Cysts and Cryptosporidium Oocysts*. Research Triangle Park, NC, EnSys Inc.

Erlandsen, S. L., L. A. Sherlock, M. Jaanuschka, D. G. Schupp, f. W. Schaefer, W. Jakubowski, and W. J. Bemrick (1988). "Cross-Species Transmission of *Giardia* spp.: Inoculation of Beavers and Muskrats with Cysts of Human, Beaver, Mouse, and Muskrat Origin." *Applied and Environmental Microbiology* **54**: 2777-2785.

Faubert, G. M., W. J. Bemrick, and S. L. Erlandsen (1988). "Is Giardiasis a True Zoonosis?" *Parasitology Today* **4**: 66-71.

Fayer, R., and B. L. P. Ungar (1986). "*Cryptosporidium* spp. and cryptosporidiosis." *Microbiological Review* **50**: 458-483.

Finch, G. R., L. L. Gyurek, L. R. J. Liyange, and M. Belosevic. (1997). *"Effect of Various Disinfection Methods on the Inactivation of Cryptosporidium."* Denver, CO. American Water Works Association Research Foundation.

Finch, G. R., E. K. Black, L. Gyurek, and M. Belosevic. (1994). *"Ozone Disinfection of Giardia and Cryptosporidium."* Denver, CO. American Water Works Association Research Foundation.

Finch, G. R., C. W. Labatiuk, R. D. Helmer, and M. Belosevic. (1992). *"Ozone and Ozone-Peroxide Disinfection of Giardia and Viruses."* Denver, CO. American Water Works Association Research Foundation.

Gammie, L. (2000). EPCOR Water Services Incorporated. Edmonton, Alberta. Personal Communication.

Garcia, L. S., T. C. Brewer, and D. A. Bruckner (1987). "Fluorescence Detection of *Cryptosporidium* Oocysts in Human Fecal Specimens Using Monoclonal Antibodies." *Journal of Clinical Microbiology* **25**(1): 119-121.

Geldreich, E. E. (1996). *Microbial Quality of Water Supply Distribution Systems*. Boca Raton, Florida, CRC Lewis Publishers.

Glicker, J. L. (1990). "Engineering and Water Quality Concerns Surface Water Source Protection." *Methods for the investigation and Prevention of Waterborne Disease Outbreaks.* U.S. Environmental Protection Agency, Washington, D.C. 157.

Goatcher, L. J., P. Poon, and E. Davis (1995). *Use of a Continuous-Flow Centrifuge System for the Determination of Giardia cysts and Cryptosporidium oocysts in Water.* 95th General Meeting of the American Society for Microbiology, Washington, D.C.

Goldstein, S. T., D. D. Juranek, and O, Ravenholt. (1996). "Cryptosporidiosis: An Outbreak Associated with Drinking Water Despite State-Of -The-Art Water Treatment." *Ann. Int. Med.* **124**: 459-468.

Goodgame, R. W., R. M. Genta, A. C. White, and C. L. Chappell (1993). "Intensity of Infection in AIDS-Associated Cryptosporidiosis." *Journal of Infectious Diseases* **167**: 704-709.

Hansen, J. S. a. J. E. O. (1991). "Effects of Time and Watershed Characteristics on the Concentration of *Cryptosporidium* Oocysts in River Water." *Applied and Environmental Microbiology* **57**(10): 2790-2795.

Hayes, E. B., T. D. Matte, T. R. O'Brien, T. W. McKinley, G. S. Logsdon, J. B. Rose, B. L. P. Ungar, D. M. Word, P. F. Pinsky, M. L. Cummings, M. A. Wilson, E. G. Long, E. S. Hurwitz, and D. D. Juranek (1989). "Large Community Outbreak of Cryptosporidiosis Due to Contamination of a Filtered Public Water Supply." *The New England Journal of Medicine* **320**: 1372-1376.

Health and Welfare Canada. (1983). "Giardiasis - Edmonton, Alberta." *Canada Diseases Weekly Report.* **9-48**:189-192.

Healy, G. R. (1979). *The Presence and Absence of Giardia lamblia cysts in Studies on Parasite Prevalence in the USA.* National Symposium on Waterborne Transmission of Giardiasis, Cincinnati, Ohio, USEPA.

Hibler, C. P. (1988). An Overview of the Techniques Used for Detection of *Giardia* spp. Cysts in Surface Waters. *Advances in Giardia Research.* P. Wallis, and B. Hammond. Calgary, Alberta, University of Calgary Press: 197-204.

Hibler, C. P., and C. M. Hancock (1990). Waterborne Giardiasis. *Drinking Water Microbiology. Progress and Recent Developments.* G. A. McFeters. New York, NY, Springer-Verlag: 271-293.

Hrudey, S. E. (1986). A Critical Assessment of Drinking Water in Edmonton. Edmonton, Alberta, Steve E. Hrudey & Associates, Ltd.

Hsu, B. M., C, Huang, C. L. L. Hsu, F. Y. Hsu, J. H. Yeh (1999). "Occurrence of *Giardia* and *Cryptosporidium* in the Kau-Ping River and its Watershed in Southern Taiwan." *Water Research* **33**(11): 1999.

Isaac-Renton, J., W. Moorehead and A. Ross (1996). "Longitudinal Studies of *Giardia* Contamination in Two Community Drinking Water Supplies: Cyst Levels, Parasite Viability, and Health Impact." *Applied and Environmental Microbiology* **62**(1): 47-54.

Isaac-Renton, J. L., C. P. J. Fung, and A. Lochan (1986). "Evaluation of a Tangential-Flow Multiple-Filter Technique for Detection of *Giardia lamblia* Cysts in Water." *Applied and Environmental Microbiology* **52**: 400-402.

Ives, L. (1990). Reservoir Storage. *Cryptosporidium in Water Supplies, Report of the Group of Experts*. J. Badenoch. London, United Kingdom, Department of the Environment, Her Majesty's Stationery Office: 160-161.

Jakubowski, W., and T. H. Ericksen (1979). Methods for the Detection of *Giardia* in Water Supplies. *Waterborne Transmission of Giardiasis*. W. Jakubowski, and J. Hoff. Cincinnati, Ohio, U.S. Environmental Protection Agency. **EPA-600/9-79-001**.

Jakubowski, W., and J. L. Cleasby (1984). *Giardia Methods Workshop*. AWWA Water Quality Technical Conference, Denver, Colorado, AWWA.

Kirkpatrick, C. E., and J. P. Farrell (1982). "Giardiasis." *Compend Contin Educ Pract Vet* **5**: 367-378.

King, M. (1989). "Modeling Time-Space Relationships: An Application of Trend Surface Analysis in an Outbreak of Giardiasis." University of Alberta Report, March, 1989.

Korich, D. G., J. R. Mead, M. S. Madore, M. A. Sinclair, and C. R. Stirling. (1990). "Effects of Ozone, Chlorine Dioxide, Chlorine, and Monochloramine on *Cryptosporidium parvum* Oocyst Viability." *Applied and Environmental Microbiology*. **56**: 1423-1428.

LeChevallier, M. W., T. M. Trok, M. O. Burns and R. G. Lee (1990). "Comparison of the Zinc Sulfate and Immunofluorescence Techniques for Detecting *Giardia* and *Cryptosporidium*." *Journal of American Water Works* Association(September): 75-82.

LeChevallier, M. W., W. D. Norton, and R. G. Lee (1991). "*Giardia* and *Cryptosporidium* spp. in Filtered Drinking Water Supplies." *Applied and Environmental Microbiology* **57**: 2610-.

LeChevallier, M. W., W. D. Norton, R. G. Lee, and J. Rose (1991). *Giardia and Cryptosporidium in Water Supplies.* Denver, Co, American Water Works Association Research Foundation and American Water Works Association.

LeChevallier, M. W., W. D. Norton, and R. G. Lee. (1991). "Occurrence of *Giardia* and *Cryptosporidium* spp. in Surface Water Supplies." *Applied Environmental Microbiology* **57**(9): 2610-2616.

LeChevallier, M. W., W. D. Norton, and T. B. Atherholt (1997). "Protozoa in Open Reservoirs." *Journal of American Water Works Association* **89**(9): 84-96.

Lengerich, E. J., D. G. Addiss, J. J. Marx, B. L. P. Ungar, and D. D. Juranek (1993). "Increased Exposure to *Cryptosporidium* Among Diary Farmers in Wisconsin." *Journal of Infectious Diseases* **167**(5): 1252-1255.

Levine, N. D. (1984). "Taxonomy and Review of the Coccidian Genus *Cryptosporidium* (Protozoa, Apicomplexa)." *Journal of Paratozoology* **31**: 94.

Lin, S. D. (1985). "*Giardia lamblia* and Water Supply." *Journal of American Water Works Association* **77**(2): 40-47.

MacKenzie, W. R., N. J. Hoxie, M. E. proctor, M. S. Gradus, K. A. Blair, D. E. Peterson, J. J. Kazmierczak, D. G. Addiss, F. R. Fox, J. B. Rose and J. P. Davis (1994). "A Massive Outbreak in Milwaukee of *Cryptosporidium* Infection Transmitted Through the Public Water Supply." *New England Journal of Medicine* **331**(3): 161-.

Madore, M. S., J. B. Rose, C. P. Gerba, M. J. Arrowood, and C. R. Sterling (1987). "Occurrence of *Cryptosporidium* Oocysts in Sewage Effluents and Selected Surface Waters." *The Journal of Parasitology* **73**(4): 702-705.

Medema, G., M. Bahar, and F. M. Schets (1997). "Survival of *Cryptosporidium* parvum, *Escherichia coli*, Faecal enterococci, and Clostridium perfringens in River Water: Influence of Temperature and Autochthonous Microorganisms." *Water, Science and Technology* **35**: 249-252.

Medema, G. J. (1998). "Sedimentation of Free and Attached *Cryptosporidium* Oocysts and *Giardia* Cysts in Water." *Applied Environmental Microbiology* **64**(11): 4460-4466.

Moore, A. C., B. L. Herwaldt, G. F. Craun, R. L. Calderon, A. K. Highsmith, and D. D. Juranek (1993). "Surveillance for Waterborne Disease Outbreaks - United States, 1991-1992." *Morbidity and Mortality Weekly Reports* **42**(SS-5): 1-22.

Musial, C. E., M. J. Arrowood, C. R. Sterling, and C. P. Gerba (1987). "Detection of *Cryptosporidium* in Water by Using Polypropylene Cartridge Filters." *Applied and Environmental Microbiology* **53**(4): 687-692.

Nieminski, E. C., F. W. Schaefer, III, and J. E. Ongerth (1995). "Comparison of Two Methods for Detection of *Giardia* Cysts and *Cryptosporidium* Oocsyts in Water." *Applied and Environmental Microbiology* **61**(5): 1714-1719.

Olson, M. E., T. A. McAllister, L. Deselliers, D. W. Morck, K.-J. Cheng, A. G. Buret and H. Ceri (1995). "Effects of Giardiasis on Production in a Domestic Ruminant (lamb) Model." *American of Journal of Veterinary Research* **56**(11): 1470-1474.

Olson, M. E., C. L. Thorlakson, L. Deselliers, D. W. Morck and T. A. McAllister (1997). "*Giardia* and *Cryptosporidium* in Canadian Farm Animals." *Veterinary Parasitology* **68**: 375-381.

Ong, C., W. Moorehead, A. Ross, and J. Isaac-Renton (1996). "Studies of *Giardia* spp. and *Cryptosporidium* spp. in Two Adjacent Watersheds." *Applied and Environmental Microbiology* **62**(8): 2798-2805.

Ongerth, J., and H. H. Stibbs (1987). "Identification of *Cryptosporidium* Oocsyts in River Water." *Applied and Environmental Microbiology* **53**(4): 672-676.

Ongerth, J. E., J. Riggs, and J. Crook (1987). *A Study of Water Treatment Practices for the Removal of Giardia lamblia Cysts*. Denver, CO, American Water Works Research Foundation.

Ongerth, J. E. (1989). "*Giardia* Cyst Concentrations in River Water." *Journal of American Water Works Association* **81**(9): 81-86.

Ongerth, J. E., G. D. Hunter, and F. B. De Walle (1995). "Watershed Use and *Giardia* Cyst Presence." *Water Research* **29**(5): 1295-1299.

Paterson, C. G., and J. R. Nursall (1975). "The Effects of Domestic and Industrial Effluents on a Large Turbulent River." *Water Research* **9**(4): 425-435.

Payment, P., A. Berube, D. Perreault, R. Armon, and M. Tudel (1989). "Concentration of *Giardia lamblia* Cysts, Legionella pneumophila, Clostridium perfringens, Human Enteric Viruses and coliphages From Large Volumes of Drinking Water Using a Single Filtration." *Canadian Journal of Microbiology* **35**: 932-935.

Peeters, J. E., E. A. Mazas, W. J. Masschelein, I. V. Martinez de Maturana, and E. Debacker. (1989). Effect of Disinfection of Drinking Water With Ozone or

Chlorine Dioxide on Survival of *Cryptosporidium parvum* Oocysts." *Applied and Environmental Microbiology*. **55**: 1519

Process Development Team. (1992). Upstream Watershed Evaluation: Interim Report - 1991. Edmonton, Alberta, The City of Edmonton, Environmental Services.

Ray, C., and K. Dykema (1991). Leopold-Maddock Equations for North Saskatchewan River Quality Study: Edmonton-Saskatchewan Border. Edmonton, Alberta, River Engineering Branch, Alberta Environment.

Rendtorff, R. D., and D. J. Holt (1954). "The Experimental Transmission of Human Intestinal Parasites IV. Attempts to Transmit Entamoeba coli *and Giardia lamblia* Cysts in Water." *American Journal of Hygiene* **60**(327).

Riggs, J. L., K. Nakamura, and J. Crook (1984). *Identifying Giardia lamblia by Immunofluorescence*. Environmental Engineering Specialty Conference, Los Angeles, California, ASCE.

Roach, P. D., M. E. Olson, G. Whitley and P. M. Wallis (1993). "Waterborne *Giardia* Cysts and *Cryptosporidium* Oocysts in the Yukon, Canada." *Applied and Environmental Microbiology* **59**(1): 67-73.

Robertson, L. J., A. T. Campbell, and H. V. Smith (1992). "Survival of *Cryptosporidium* parvum oocysts Under Various Environmental Pressures." *Applied and Environmental Microbiology* **58**(3494-3500).

Rose, J. B., C. Musial, M. J. Arrowood, C. R. Sterling, and C. P. Gerba (1985). *Development of a Method for the Detection of Cryptosporidium in Drinking Water*. AWWA Water Quality Technical Conference, Houston, TX, AWWA.

Rose, J. B., M. S. Madore, J. L. Riggs, and C. P. Gerba (1986). *Detection of Cryptosporidium and Giardia in Environmental Waters*. AWWA WQTC, Portland, Oreg., AWWA.

Rose, J. B., A. Cifrino, M. S. Madore, C. P. Gerba, C. R. Sterling, and M. J. Arrowood (1986). "Detection of *Cryptosporidium* from Wastewater and Freshwater Environments." *Water Science and Technology* **18**(10): 233-239.

Rose, J. B., H. Barbin, and C. P. Gerba (1988). *Correlations of the protozoa, Cryptosporidium and Giardia with water quality variables in a watershed*. International Conference on Water and Wastewater Microbiology, Newport Beach, California.

Rose, J. B., D. Kayed, M. S. Madore, C. P. Gerba, M. J. Arrowood, C. R. Sterling, and J. L. Riggs (1988). Methods for the Recovery of *Giardia* and

Cryptosporidium from Environmental Waters and Their Comparative Occurrence. Cincinnati, Ohio, USEPA.

Rose, J. B., D. Kayed, M. S. Madore, C. P. Gerba, M. J. Arrowood, C. R. Sterling, and J. L. Riggs (1988). Methods for the Recovery of *Giardia* and *Cryptosporidium* from Environmental Waters and their Comparative Occurrence. *Advances in Giardia Research*. P. Wallis, and B. Hammond. Calgary, Alberta, University of Calgary Press: 205-209.

Rose, J. B. (1988). "Occurrence and Significance of *Cryptosporidium* in Water." *Journal of American Water Works Association* **80**: 53-58.

Rose, J. B., L. K. Landeen, K. R. Riley, and C. P. Gerba (1989). "Evaluation of Immunofluorescence Techniques for Detection of *Cryptosporidium* oocysts and *Giardia* Cysts from Environmental Samples." *Applied and Environmental Microbiology* **55**(12): 3189-3196.

Rose, J. B. (1990). Occurrence and Control of *Cryptosporidium* in Drinking Water. *Drinking Water Microbiology. Progress and Recent Developments*. G. A. McFeters. New York, NY, Springer-Verlag: 294-321.

Rose, J. B., C. P. Gerba and W. Jakubowski (1991). "Survey of Potable Water Supplies for *Cryptosporidium* and *Giardia*." *Environmental Science and Technology* **25**(8): 1393-1400.

Rose, J. B. (1997). "Environmental Ecology of *Cryptosporidium* and Public Health Implications." *Annual Review of Public Health* **18**: 135-161.

Rose, J. B., J. T. Lisle, and M. LeChevallier (1997). Waterborne Cryptosporidiosis: Incidence, Outbreaks and Treatment Strategies. *Cryptosporidium and Cryptosporidiosis*. R. Fayer. Boca Raton, Fla, CRC Press.

Rutter, N. W., and S. Thomson (1982). "Effects of Geology on the Development of Edmonton, Alberta, Canada." *Geology Under Cities, Reviews in Engineering Geology* **5**: 55-61.

Sauch, J. F. (1985). "Use of Immunofluorescence and Phase-Contrast Microscopy for Detection and Identification of *Giardia* Cysts in Water Samples." *Applied and Environmental Microbiology* **50**: 1434-1438.

Schmidt, G. D. a. L. S. R. (1977). *Foundations of Parasitology*. St. Louis, Mo, C.V. Mosby Co.

Shaw, P. K., R. E. Brodsky, D. O. Lyman, B. T. Wood, C. P. Hibler, G. R. Healy, K. I. E. MacLeod, W. Stahl, and M. G. Schultz (1977). "A Community Wide

Outbreak of Giardiasis With Evidence of Transmission by a Municiple Water Supply." *Ann. Intern. Med* **87**: 426-432.

Shaw, R. D., P. A. Mitchell, and A. M. Anderson (1994). *Water Quality of the North Saskatchewan River*. Edmonton, Alberta, Alberta Environmental Protection.

Sischo, W. M., E. R. Atwill, L. E. Lanyon, and J. George. (2000). " Cryptosporidia on Dairy Farms and the Role These Farms may Have in Contaminating Surface Water Supplies in the Northeastern United States." *Preventative Veterinary Medicine* **43**:253-267.

Spaulding, J. J., R. E. Pacha, and G. W. Clark (1983). "Quantification of *Giardia* spp. Cysts by Membrane Filtration." *Applied and Environmental Microbiology* **18**: 713-715.

Smith, H., and J. Rose. (1990). "Waterborne Cryptosporidiosis." *Parasitology Today*. **6**: 8-12.

Sterling, C. R., and M. J. Arrowood (1986). "Detection of *Cryptosporidium* spp. Infections Using a Direct Immunofluorescent Assay." *Pediatric Infectious Disease* **5**(1): S139-S142.

Sterling, C. R., R. M. Kutob, M. J. Gizinski, M. Verastequi, and L. Stetzenbach. (1988). *Giardia* spp. detection using monoclonal antibodies recognizing determinants of in vitro derived cysts. *Advances in Giardia Research*. a. B. H. P. Wallis. Calgary, Alberta, University of Calgary Press: 219-222.

Stibbs, H. H., and J. E. Ongerth (1986). "Immunofluorescence Detection of *Cryptosporidium* Oocsyts in Fecal Smears." *Journal of Clinical Microbiology* **24**(4): 517-521.

Sykora, J. L., S. J. States, W. D. Bancroft, S. N. Boutros, M. A. Shapiro, and L. F. Conley (1986). *Monitoring of Water and Wastewater for Giardia*. AWWA WQTC, Portland, Ore.

Sykora, J. L., W. Jakubowski, C. A. Sorber, C. M. Clancy, and P. D. Gavaghan (1988). *Monitoring of Environmental Samples for Giardia cysts*. Fourth Conference on Progress in Chemical Disinfection, Binghamton, New York.

Sykora, J. L., C. A. Sorber, W. Jakubowski, L. W. Casson, P. D. Gavaghan, M. A. Shapiro, and M. J. Schott (1991). "Distribution of *Giardia* Cysts in Wastewater." *Water Science and Technology* **24**(2): 187-192.

Tyzzer, E. E. (1907). "A Sporozan Found in the Peptic Glands of the Common Mouse." Proceedings of the Society of Experimental Biology and Medicine **5**: 12-13.

Ungar, B. L. P. (1994). *Cryptosporidium* and Cryptosporidiosis. *Textbook of AIDS Medicine*. S. Broder, T. C. Merigan Jr., and D. Bolognesi. Baltimore, Md, Williams and Wilkins.

USEPA (1995). ICR Protozoan Method for Detecting *Giardia* Cysts and *Cryptosporidium* Oocsyts in Water by a Fluorescent Antibody Procedure. Cincinnati, OH, Office of Ground Water and Drinking Water, USEPA: 60.

USEPA (1995). Information Collection Requirements Rule - Protozoa and Enteric Virus Sample Collection Procedures. Washington, DC, Office of Ground Water and Drinking Water, USEPA: 63.

USEPA (1997). Method 1622: *Cryptosporidium* in Water by Filtration/IMS/FA - Draft. Washington, DC, Office of Water, USEPA: 51.

van Roodselaar, A. (1998). Water Treatment and the *Giardia* Cyst. *Advances in Giardia Research*. P. M. Wallis, and B. R. Hammond. Calgary, Alberta, University of Calgary Press: 85-86.

Vesey, G., J. S. Slade, m. Byrne, K. Sheperd, and C. R. Fricker (1993). "A New Method for the Concentrations of *Cryptosporidium* Oocsyts from Water." *Journal of Applied Bacteriology* **75**: 82-86.

Wallis, P. M., S. L. Erlandsen, J. L. Isaac-Renton, M. E. Olson, W. J. Robertson, and H. van Keulen. (1996). "Prevalence of *Giardia* Cysts and *Cryptosporidium* Oocysts and Characterization of *Giardia* spp. Isolated from Drinking Water in Canada." *Applied and Environmental Microbiology*. **62**(8): 2789-2797.

Walker, F. R., Jr., and J. R. Stedinger (1999). "Fate and Transport Model of *Cryptosporidium*." *Journal of Environmental Engineering* **125**(4): 325-333.

Weniger, B. G., M. J. Blaser, and J. Gedrose (1983). "An Outbreak of Waterborne Giardiasis Associated With Heavy Water Runoff Due to Warm Weather and Volcanic Ashfall." *American Journal of Public Health* **73**: 868-872

Whitehead, T. (1997). *Water Quality Study of Strawberry Creek*. Master of Engineering Report. University of Alberta, Edmonton, Alberta.

Xiao, L. (1994). "*Giardia* Infection in Farm Animals." *Parasitology Today* **10**: 436-438.

Appendix A Methods for Detecting *Cryptosporidium* spp. Oocsyts and *Giardia* spp. Cysts

A.1 ICR Method for Source and Treated Drinking Water

A.2 Continuous Centrifugation Method for Sewage Effluent Samples

A.1 ICR Method for Source and Treated Drinking Water

Filter Washing and Flotation Purification

After collection, the filter along with the filter housing water was placed in a Glad zip-lock bag (Glad, Canadian Tire, Alberta, Canada). The filters were double-bagged and shipped to the laboratory via overnight delivery. After deliver, the samples were stored at 4 °C and usually processed within 24 to 96 hours.

To prepare samples for analysis, the residual solution in the sample bag (filter housing) is poured into a beaker, and the bag is rinsed with eluting solution and added to the beaker. The sample bag is discarded. The filters were cut in half lengthwise to the plastic core using a sterile surgical scalpel to produce fibers approximately 51 mm long. The filter core is rinsed with eluting solution into the beaker containing residual solution from the filter bag. Fibers were teased apart and placed in a 3,500-mL capacity sterile Stomacher bag with 1.75 L of eluting solution (Buffered Detergent Solution (BDS, pH 7.4)) containing 0.1 percent sodium dodecyl sulfate (SDS, Sigma Aldrich Canada, Cat # L5750) and 0.1 percent Tween 80 (Sigma Aldrich Canada, Cat # P1754) and homogenized in a Stomacher Lab Blender (model 3500) for two 5-min intervals over a 15 min period. In between each homogenization period, the filter material was hand kneaded to redistribute the fibers in the bag. After the second homogenization, the eluted particulate suspension is poured into a 4 L pooling beaker. The fibers are wrung out to express as much of the liquid as possible. The fibers are

returned to the stomacher bag and 1 L of eluting solution is added. Homogenization occurs for an additional two 5 min periods. Between each homogenization period, the fiber materials are hand kneaded to redistribute them in the bag. At the end of the second homogenization period, the eluted particulate suspension is added to the 4 L pooling beaker. The fibers are wrung out to express as much of the liquid as possible into the beaker. The fibers are discarded, and the stomacher bag is rinsed with eluting solution and added to the pooling beaker.

The eluate from the pooling beaker is combined with the residual water. The liquid is then poured into a conical centrifuge bottle. The combined eluate and residual water is concentrated into a single pellet by centrifugation at 1, 050 x g for 10 minutes in a plastic conical centrifuge bottle using one of the following four centrifuges: 1) a 250 mL capacity IEC HN-SII; or 2) a 15 to 500 mL capacity IEC Centra 8; or 3) a 15 to 500 mL capacity IEC Centra 8R; or 4) a 15 to 500 mL K Model Centrifuge (all from Fisher Scientific, Edmonton, Alberta). At the end of the 10 min, the supernatant fluid is aspirated and discarded. The pellet is resuspended in sufficient elution solution by vortexing, this prevents excessive packing of the particulates that form the pellet. The centrifugations of the pooled eluate and residual water is continued at 1 050 x g for 10 min until all the particulates are concentrated in one conical bottle. At this point the packed pellet volume is recorded. The supernatant fluid is aspirated and discarded, and the pellet is resuspended by vortexing in an equal volume of 10 % neutral buffered

formalin solution. If the packed pellet volume is less than 0.5 mL, the pellet solution volume is brought to 0.5 mL with eluting solution before adding enough 10 % neutral buffered formalin (NBF) solution to bring the resuspended pellet volume to 1.0 mL.

The 10 % NBF is made by dissolving 0.762 g disodium hydrogen phosphate (Na_2HPO_4), 0.019 g sodium dihydrogen phosphate (NaH_2PO_4), and 100 mL formalin in water to a final volume of 1 L.

The volume of resuspended pellet equivalent to not more than 0.5 mL of packed pellet volume is vortexed with enough eluting solution to make a final volume of 20 mL. The 20 mL vortexed suspension of particulates is underlayed with 30 mL of Percoll-sucrose flotation solution (specific gravity 1.1) using a 50 mL syringe and 14 gauge cannula. The preparation is centrifuged at 1, 050 x g for 10 min using a swinging bucket rotor. The centrifuge is slowly accelerated, and the brake is not used in this step as to not disrupt the pellet suspension/Percoll-sucrose interface. The top 20 mL of the particulate suspension layer, the interface, and 5 mL of the Percoll-sucrose below the interface are drawn off using a polystyrene 25 mL pipette rinsed with eluting solution. The final volume is brought to 50 mL by adding additional eluting solution to the centrifuge tube. The sample is then centrifuged at 1 050 x g for 10 min. The supernatant fluid is aspirated down to 5 mL (plus pellet) and discarded.

The Percoll-Sucrose Flotation Suspension was prepared by addition of 45 mL Percoll (sp. Gr. 1.13; Sigma Aldrich Canada Cat. # P 1644), 45 mL water and 14 mL 2.5 M sucrose solution. The specific gravity of the solution was checked using a hydrometer . The Percoll-sucrose solution was maintained at 4 °C and used within a week.

Indirect Fluorescent Antibody (IFA) Procedure

The sample volume concentrated from the flotation purification procedure is determined for each 25-mm diameter membrane filter used in the IFA assay (Sterling 1987; Sauch 1985; Ong 1996). The sample concentrate is vortexed and 40 µL is applied to one 5-mm diameter well of a 12 well red heavy teflon coated slide. The sample is allowed to sit for approximately 2 minutes at room temperature. The flooded well is examined microscopically at 200 x total magnification to determine if the particulates are distributed evenly over the well surface. Volumes of unevenly distributed samples are adjusted accordingly, and another well is retested. If they are evenly distributed, 1 mL of the undiluted sample is applied to a 25 mm diameter membrane.

The filtration manifold is connected to the vacuum supply using a vacuum tube that has a "T" shaped tubing connector at one end. The Hoffman screw clamp is attached to 4o to 60 mm of the latex tubing and then the latex tubing is attached to the stem of the "T" connector. The screw clamp is used as a bleeder valve to regulate the vacuum to 50 to100 mm of mercury (Hg). All manifold valves are

closed and the vacuum is opened all the way. The bleeder valve on the vacuum tubing is used to adjust the applied vacuum to 50 to 100 mm of Hg.

One Sartorius 25 mm diameter cellulose acetate filter, 0.22 μm pore size, and one 25 mm diameter ethanol-compatible membrane support filter, any porosity, are required for each 1 mL of adjusted suspension obtained above. The filters are soaked separately in Petri dishes filled with 1 x PBS. The filters are dropped one by one flat on the surface of the buffer using blunt-end filter forceps. The filtration manifold vacuum source is turned on, and one support filter is placed on each manifold support screen to ensure even distribution of the sample. One Sartorius 25 mm diameter cellulose acetate filter is placed on top of each support filter. A rubber policeman is used to adjust the cellulose acetate filter, as necessary. The manifold well support valves are opened to flatten the filter membranes, making sure that no bubbles are trapped and that there are no creases or wrinkles on any of the filter membranes. One positive control for *Giardia* spp. cysts and *Cryptosporidium* spp. oocysts and one negative control is included each time the manifold is used. A 454 g stainless steel well is firmly positioned over each filter and labeled appropriately with little pieces of tape on top of the well to keep track of each sample and control.

The manifold support valve for each well containing filter is opened and the inside of each stainless steel well and membrane filter is rinsed with 2 mL of 1% Bovine Serum Albumin (BSA). The BSA is completely drained from the

membrane and the manifold valve under each membrane filter is closed. For the positive control, the Ensys positive control antigen, was used as specified in EnSys Hydroflour Combo Kit (Cat # SD 7081000, Oxoid, Nepean, ON) (EnSys Inc. Environmental Products, 1995). For a negative control, to the appropriately labeled well 1.0 mL 1 x PBS was added. For the samples, 1.0 mL of the vortexed, adjusted water sample is added o the appropriately labeled wells. The manifold valve under each membrane filter is opened to drain the wells. The wells are rinsed with 2 mL 1% BSA, then the manifold valves under each membrane filter is closed.

The 1% BSA is made by sprinkling 1.0 g BSA crystals over 85 mL 1 x PBS, pH 7.4. The crystals are allowed to fall before stirring into solution with a magnetic stir bar. After the BSA is dissolved, the volume is adjusted to 100 mL with PBS. For prolonged storage, sterilize by filtering through a 0.22 μm membrane filter into a sterile tube or bottle. The solution may be stored at 4 °C for up to 6 months.

The primary antibody mixture and labeling reagents are diluted according to the manufacturer's instructions using 1xPBS. The 0.5 mL of the diluted primary antibody mixture is pipetted onto each membrane and allowed to remain in contact with the filter for 25 minutes at room temperature. At the end of the contact period, the manifold valve is opened to drain the antisera. Each well and filter is rinsed 5 times with 2 mL 1 x PBS. The manifold valves are closed after

the last wash is completed. Then 0.5 mL of the labeling reagent is pipetted onto each membrane and allowed to remain in contact with the filter for 25 minutes at room temperature, then the manifold valves are opened to allow the labeling reagent to drain. The wells are covered with aluminum foil to shield the reagents form light and to prevent dehydration and crystallization of the fluorescein isothiocyanate dye during the contact period. Each well is rinsed 5 times with 2 mL 1 x PBS. The manifold valve is closed after the last wash is completed.

Microscopic Examination

The membrane filters in each well are dehydrated by sequentially applying 1.0 mL of 10, 20, 40, 80, and 90.2 % ethanol solutions containing 5 % glycerol. Each solution is allowed to drain thoroughly before applying the next series. Glass slides were labeled for each filter and placed on slide warmers or in an incubator calibrated for 37 °C. Filters cleared by applying 75 μL 2% DABCO-glycerol mounting medium to each slide on the slide warmer or in the incubator and allowed to warm for 20-30 minutes.

The 2 % DABCO-Glycerol Mounting Medium is prepared by prewarming 95 mL of glycerol using a magnetic stir bar on a heating stir plate. 2 g of 1,4 diazabicyclo[2,2,2] octane (DABCO, Sigma Aldrich Canada #D-25220 to the warm glycerol with continuous stirring until it dissolves. The final volume is adjusted to 100 mL with additional glycerol. The solution is stored at room temperature and is used up to 6 months.

The top cellulose acetate filter is layered over the correspondingly labeled slide prepared with DABCO-glycerol mounting medium. The slides remain on the warmer or in the incubator for 20 minutes in order to clear. After the 20-min clearing period, apply 20 µL DABCO-glycerol mounting medium to the center of each membrane filter and cover with a 25 mm x 25 mm cover glass. Tap out air bubbles with the handle end of a pair of forceps. The excess DABCO-glycerol mounting medium is wiped off the edges of each cover glass with a slightly moistened Kimwipe. The edges of each cover glass is sealed to the slide with clear fingernail polish (purchased locally). The slides are stored in a covered "dry box" at 4 °C. The slides are examined microscopically as soon as possible, but within 5 days of preparation.

For proper microscopic examination, the dry box is removed from storage at 4 °C and allowed to warm to room temperature before opening it up. The entire coverslip is scanned using epifluorescent at not less than 200 x total magnification for apple-green fluorescence of cyst and oocyst shape. When brilliant apple-green fluorescing round-to-oval objects (8 to 18 µm long by 5 to 15 µm wide) with brightly highlighted edges are observed, the switch to Hoffman modulation® and/or differential interference contrast (D.I.C) is made. EPCOR Water Services has one microscope equipped to use Hoffman modulation® and one equipped to use D.I.C. External or internal morphological characteristics atypical of *Giardia* spp. cysts are looked for (e.g., spikes, stalks, appendages,

pores, one or two large nuclei filling the cell, red fluorescing chloroplasts, crystals, spores, etc.). If these atypical structures are not observed, then categorize such apple-green fluorescing objects of the aforementioned size and shape as either empty *Giardia* spp. cysts, *Giardia* spp. cysts with amorphous structure, or *Giardia* spp. cysts with internal structures (nuclei, axonemes, and median bodies). The shape and measurement (to the nearest 0.5 μm at 1, 000 x total magnification) for each such object is recorded, as well as the internal structures observed. Sum the counts of empty *Giardia* spp. cysts, *Giardia* spp. cysts with amorphous structure, and *Giardia* spp. cysts with internal structures. Report this sum as the total *Giardia* spp. IFA count.

When brilliant, apple-green fluorescing ovoid or spherical objects (3 to 7 μm in diameter) with brightly highlighted edges are observed, switch the microscope to the Hoffman modulation® and/or D.I.C. optics. Look for external or internal morphological characteristics atypical of *Cryptosporidium* spp. oocysts (e.g., spikes, stalks, appendages, pores, one or two large nuclei, filling the cell, red fluorescing chloroplasts, crystals, spores, etc.). If these atypical structures are not observed, then categorize such apple-green fluorescing objects of the aforementioned size and shape as either empty *Cryptosporidium* spp. oocysts, *Cryptosporidium* spp. oocysts with amorphous structure, or *Cryptosporidium* spp. oocysts with internal structure (1 to 4 sporozoites/oocysts).

Record the shape and measurements (to the nearest 0.5 μm at 1, 000 x total magnification) for each such object. Record the number of sporozoites observed. Sum the counts of empty *Cryptosporidium* spp. oocysts, *Cryptosporidium* spp. oocysts with amorphous structure, and *Cryptosporidium* spp. oocysts with internal structure. Report this sum as the total *Cryptosporidium* spp. IFA count.

Densities of parasites were reported as number/100 L for all samples. When parasites were not detected, the parasite level was reported as less than the detection limit. Unless stated differently, presumptive counts (based on fluorescence) are presented, and values are not adjusted to reflect recovery efficiencies.

A.2 Sewage Effluent Sample Processing

The method used to procedure concentrated sewage effluent samples by continuous flow centrifugation for the detection and enumeration of *Giardia* spp. cysts and *Cryptosporidium* spp. oocysts was developed in house by EPCOR Water Services Incorporated (Goatcher 1995). Samples are analyzed for the presence of parasites using the ICR Method IPA-814-B-95-003 (USEPA 1995). Results obtained by this method are affected by sample turbidities, therefore failure to detect organisms of interest and/or a low detection limit does not ensure that the sewage effluent is pathogen-free.

All samples may be stored at 4 °C for a maximum of 72 hours, at which time they must be processed. After confirmation of validity and completeness of data provided with sample, assemble the continuous-flow centrifuge head as directed in the Heraeus 17 RS operating manual. The carboy is positioned near the centrifuge and the silicone tubing is attached to the appropriate entry port on the lid of the centrifuge head, passing through the peristaltic pump head. The centrifuge is then programmed as directed in the manual for speed and time required (for most samples, 10, 000 rpm (8, 385 x g) and 400 mL/min rate). The centrifuge process is started and the peristaltic pump is turned on, ensuring the pump is connected to the side port of the centrifuge to ensure pumping action when the speed is great enough to produce 400 mL per min. The centrifugation process is continued until the carboy is almost empty. The carboy is tipped to

remove the remaining sample. The carboy is rinsed three times with 500 mL of reagent grade water. If more sample needs to be processed, transfer the intake tubing to the new carboy and proceed as above. The carboys are continued to be alternated until the desired sample volume is processed. The rate of concentration is approximately 20 L per hour. After the sample processing is completed, the centrifuged is stopped and the head is removed as shown in the instruction manual and transferred to a biohazard hood.

The centrifuge head is disassembled as described in the manual. The sediment in the bottom of the centrifuge head bowl is removed using the scraping tool provided. The contents are transferred into a 250 or 500 mL conical bottom centrifuge bottle. Then, wash down with a minimum amount of reagent water and transfer washing to rest of sample in bottles. The concentrating of the sample is performed at 1, 050 x g for 12 min. (ICR method) until a single pellet is obtained. The pellet packed volume is recorded and the supernatant fluid is discarded. The pellet is re-suspended by vortexing with an equal volume of 10% NBF solution. If the packed pellet volume was less than 0.5 mL, enough eluant was added to bring the volume to 0.5 mL, then 0.5 mL of NBF is added to bring the resuspended pellet volume to 1.0 mL. From this point, the sample purification, Fluorescent Antibody Staining, Microscopic examination and calculations are the same as described in the ICR method and above.

Appendix B: Wastewater Treatment Plants Descriptions and Layouts

B.1 Rocky Mountain House

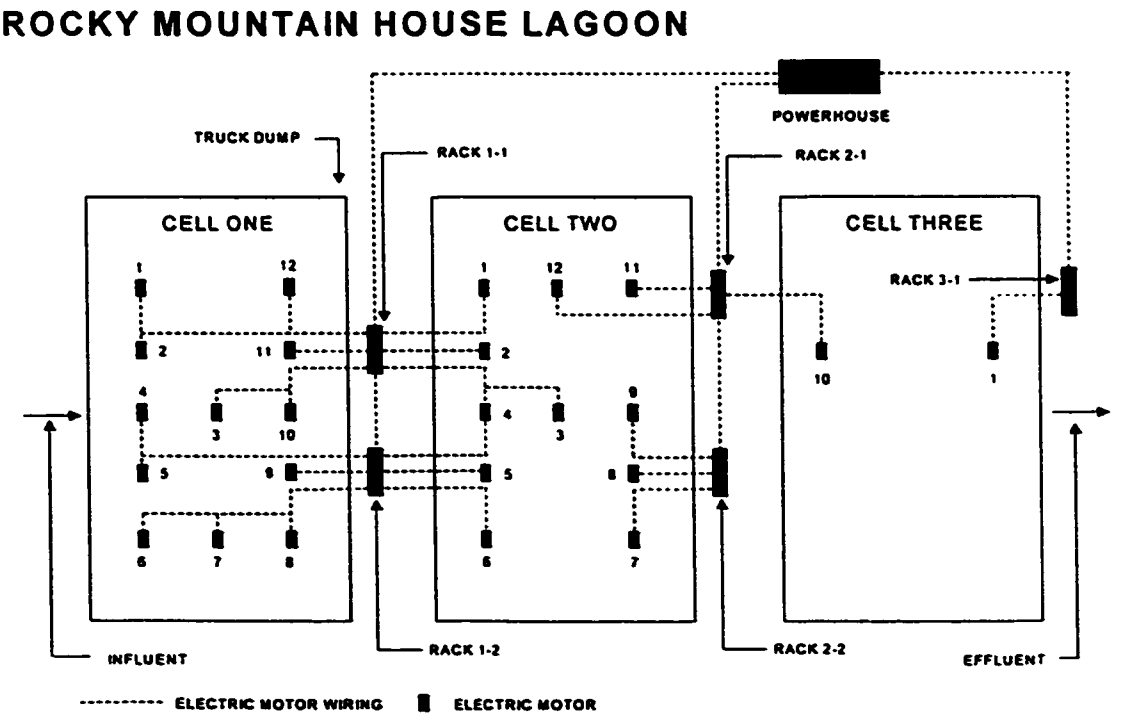
B.2 Drayton Valley

B.3 Devon

B.4 Goldbar

B.1 Rocky Mountain House WWTP

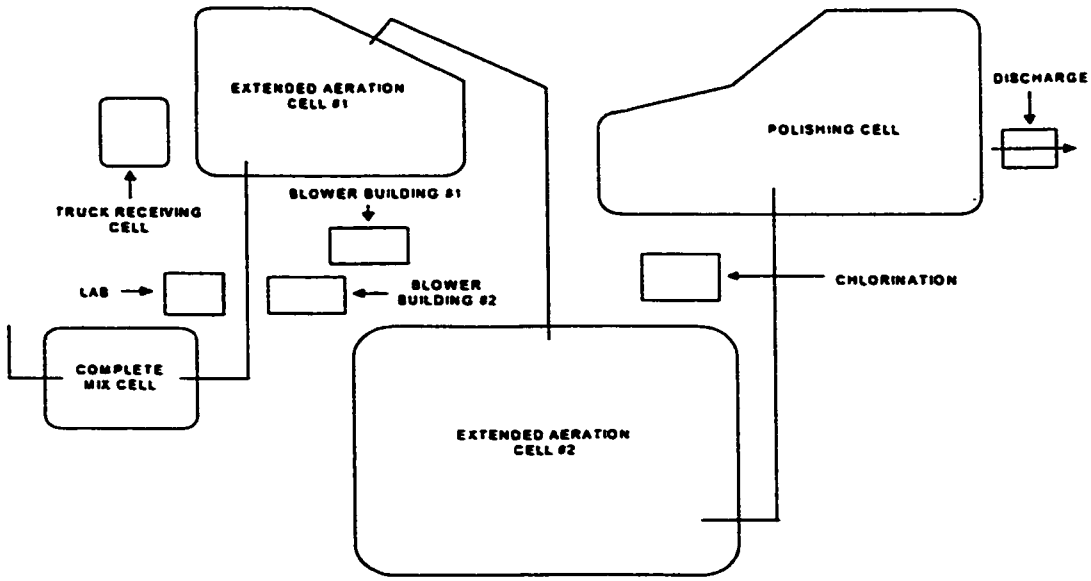
The Rocky Mountain House WWTP, identified as star "A" in Figure 3.2, is located in the town of Rocky Mountain House, Alberta, and is used to support approximately 6062 people in the town and its surrounding areas. The WWTP receives less than one percent of its wastewater from a meat packing plant, five percent of its wastewater from car-washes and the rest is made up solely of human wastewater. The municipal wastewater is delivered to the facility through a sewage pipeline collection system and through vacuum trucks. The facility was built in 1970 and went through an upgrade in 1987 where the original pond was divided into three cells and 26 aerators were added. The aerated retention pond process has minimal sludge production. The design capacity of the upgraded facility is 3.75 ML/day.



B.2 Drayton Valley WWTP

The Drayton Valley WWTP, identified as star "B" in Figure 3.2, is located in the city of Drayton Valley, Alberta, and is used to support approximately 7000 people within the city and its surrounding areas. The WWTP does not receive any industrial waste or agricultural waste, it only accepts municipal wastewater. The municipal waste is delivered to the facility via a gravity driven pipe collection system (99%) and a very small amount is trucked to the facility via honey wagons (1%). The Drayton Valley WWTPs processes include a complete mix aeration cell and two extended aeration cells. Gas chlorination is followed by a polishing cell and the discharge is continuous. The facility was built in 1972 and was upgraded in 1988 to its present configuration. The WWTP has a design capacity of 15 ML for the extended aeration lagoons. The sewage sludge at this facility is minimal in volume due to the facultative aeration process used at this facility. Occasional pond remediation requires on-site drying.

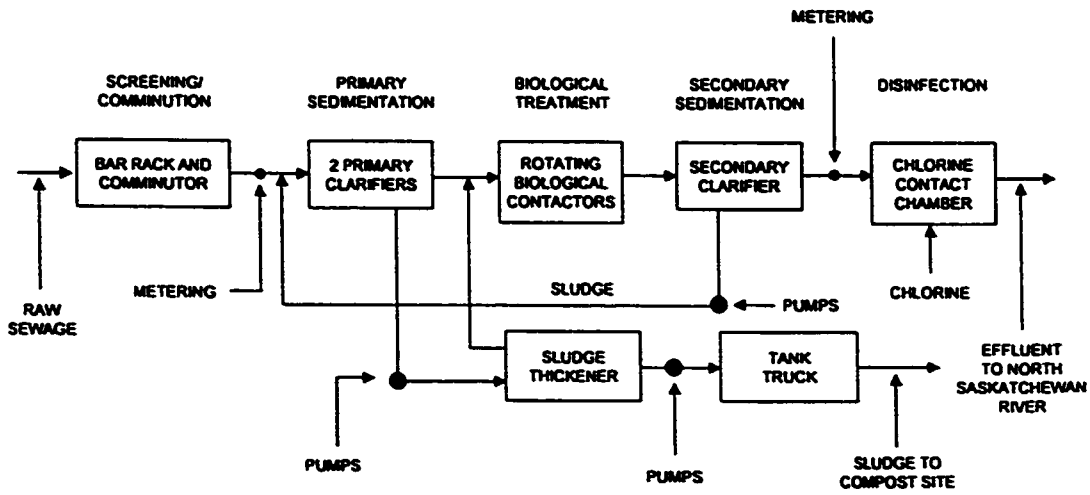
DRAYTON VALLEY WASTEWATER TREATMENT PLANT



B.3 Devon WWTP

The Devon WWTP, identified as star "C" in Figure 3.2, is located in the town of Devon and is used to support approximately 5000 people in the town and its surrounding areas. The WWTP was built in 1963 and has undergone expansions in 1978 and 1993. At present the processes used at the WWTP include screens, comminutors, two primary clarifiers, four rotating biological contractor units, one secondary clarifier, and a gas chlorine contact chamber. The bio-solids are removed and composted off site by KC Environmental in Edmonton, Alberta. The present design capacity of the WWTP is 3.9 ML/day. The WWTP accepts municipal wastewater and does not accept agricultural or industrial wastewater. The wastewater is piped in via sanitary lines, and there are some combined sanitary and storm sewers feeding into the facility. There are a very small number of honey wagons that actually truck in human waste from areas such as campgrounds and such.

DEVON WASTE WATER TREATMENT PLANT



B.4 Goldbar WWTP

The Gold Bar WWTP, identified as star "D": in Figure 3.2, was built in 1956 as a 19.5-hectare Class IV secondary waste-activated sludge treatment plant and originally handled waste for 250 000 people. The facility underwent expansions in the 1960s and again in 1981. At present it has a current design capacity of 310 ML/day. In 1994 Gold Bar began its upgrading to a tertiary treatment facility and hopes its upgrades will be completed by 2005 to meet new effluent quality standards. With the increase to primary treatment capacity, the Gold Bar WWTP will be capable of handling peak primary flows of up to 1600 ML/day.

Appendix C: Sewage Treatment Lagoon Descriptions

C.1 Alderflats

C.2 Birchwood Village

C.3 Breton

C.4 Buck Creek

C.5 Violet Grove

C.6 Calmar

C.7 Rocky Rapids

C.8 Sunnybrook

C.9 Thorsby

C.10 Tomahawk (main)

C.11 Tomahawk (school)

C.12 Warburg

C.13 Winfield

C.1 Alderflats STL

The Aldergrove STL, identified as star "E" in Figure 3.2, is located with in the town of Aldergrove. It serves a population of 140 people and has a storage cell capacity of 26 800 m^3. It accepts only human waste and 90% of it is piped in via sanitary collection system, and 10% is trucked in to the lagoon by honey wagons. The lagoon discharges into Rose Creek, which flows directly into the North Saskatchewan River. The lagoon is permitted 1 discharge per year during the period of April 1 to November 30 each year for no longer than three weeks. It has discharged in 1998 and 1999 during the study. The Aldergrove STL has no sludge management plan at present, has not had to remove sludge. The lagoon effluent was sampled in 1999, however not in 1998. As for historical discharges, the lagoon did discharge in 1997, 1996 and 1995.

C.2 Birchwood Village STL

The Birchwood Village STL, identified as star "I" in Figure 3.2, is located in the hamlet of Birchwood Village, Alberta and serves a population of 70 people in the hamlet and its surround area. It has a storage cell capacity of 19 120 m^3. It accepts 99% human waste, and 1% industrial waste. All wastewater is trucked to the lagoon via honey wagons. At present, there is no sludge management practices at the lagoon. The Birchwood Village STL discharges into Modeste Creek, which flows directly into the North Saskatchewan River. The lagoon is permitted one discharge per year from April 1 to November 30 each year for no longer than three weeks. The lagoon did not discharge in 1998 or 1999, and

therefore the effluent was not sampled during the study. As for historical discharges, it did not discharge in 1997, 1996 or 1995

C.3 Breton STL

The Breton STL, identified as star "L" in Figure 3.2, is located in the town of Breton, Alberta and serves a population of 521 people in the town and its surrounding area. It has a storage cell capacity of 90 000 m^3. It accepts 100% human waste, and wastewater is trucked and piped directly to the lagoon. At present, there are no sludge management practices at the lagoon. The Breton STL discharges into Modest Creek, which flows directly into the North Saskatchewan River. The lagoon is permitted 2 discharges per year between April 1 and November 30 each year for no longer than three weeks each time. The lagoon discharged only once in 1999 and in 1998. However, the lagoon was sampled only during 1999 for this study. As for historical discharges, the lagoon discharged in

C.4 Buck Creek STL

The Buck Creek STL, identified as star "F" in Figure 3.2, is located in the village of Buck Creek, Alberta, and serves a population of 100 people in the village and its surrounding areas. It has a storage cell capacity of 24 313 m^3. It accepts 99% human and municipal waste, and 1% industrial waste. All wastewater is piped into the lagoon via a sanitary collection system. The lagoon is permitted to discharge once per year during the period of April 1 to November 30, for no longer than three weeks each year. The lagoon discharges into an Unnamed

Creek, which flows directly into the North Saskatchewan River. At present there are no sludge management practices at the lagoon. This is a new lagoon that was built in 1996. The old lagoon discharged for the last time in 1995, however still collected wastewater until the new lagoon was commissioned in 1996. The old lagoon has resident ducks, muskrats and beaver living with in its cell. At present there is no plan of discharging the old lagoon and decommissioning it. The lagoon did not discharge during 1998, but did discharge in 1999. The lagoon was sampled not sampled in 1999 during its discharge. As for historical discharges, the lagoon did not discharge in 1997 or 1995, and did discharge in 1996.

C.5 Violet Grove STL

The Violet Grove STL, identified as star "G" in Figure 3.2, is located in the small town of Violet Grove, Alberta and serves a population of 80 people in the town and its surrounding area. The lagoon has a storage cell capacity of 25 000 m^3. It accepts 99% human waste and 1% industrial waste, all of which is piped into the lagoon. The lagoon is permitted to discharge once per year form the period of April 1 to November 30 for a maximum of three weeks. The lagoon discharges into an Unnamed Creek, which flows directly into the North Saskatchewan River. At present there is no sludge management practices at the lagoon. The lagoon discharged in 1999, but not in 1998, it was sampled during its discharge in 1999. As for historical discharges, the lagoon discharged in 1997 and 1995, and did not discharge in 1995.

C.6 Calmar STL

The Calmar STL, identified as star "Q" in Figure 3.2, is located in the town of Calmar, Alberta, and serves a population of 1800 people in the town and its surrounding areas. The lagoon has a storage cell capacity of 239 425 m^3. It accepts 100% human waste, all of which is piped into the lagoon. The lagoon is permitted one discharge per year during the period of April 1 to November 30 each year and for no longer than three weeks. The lagoon discharges into Conjuring Creek, which flows directly into the North Saskatchewan River. The lagoon's sludge management practices include field application, and the rates of application are unknown at present. The lagoon discharged in 1998 and in 1999 and its effluent was sampled once during the study in 1999. As for historical discharges, the lagoon discharged in 1997, 1996 and 1995

C.7 Rocky Rapids STL

The Rocky Rapids STL, identified as star "H" in Figure 3.2, is located in the small town of Rocky Rapids, Alberta, and serves a population of 130 people in the town and its surrounding areas. It ahs a storage capacity of 54 000 m^3. It accepts 99% human and municipal waste, and 1% industrial waste. All wastewater is piped into the lagoon via sanitary sewage collection system. At present the lagoon's sludge management practices include land application, however the rate of application is unknown. The lagoon is permitted to discharge once per year between the period of April 1 and November 30 for a maximum of three weeks. The lagoon discharges into an Unnamed Creek, which flows directly into the North Saskatchewan River. The lagoon did not discharge in

1998, but did discharge in 1999. The lagoon effluent was sampled in 1999 during its discharge period. As for historical discharges, the lagoon discharged in 1997 and 1995, but did not discharge in 1996

C.8 Sunnybrook STL

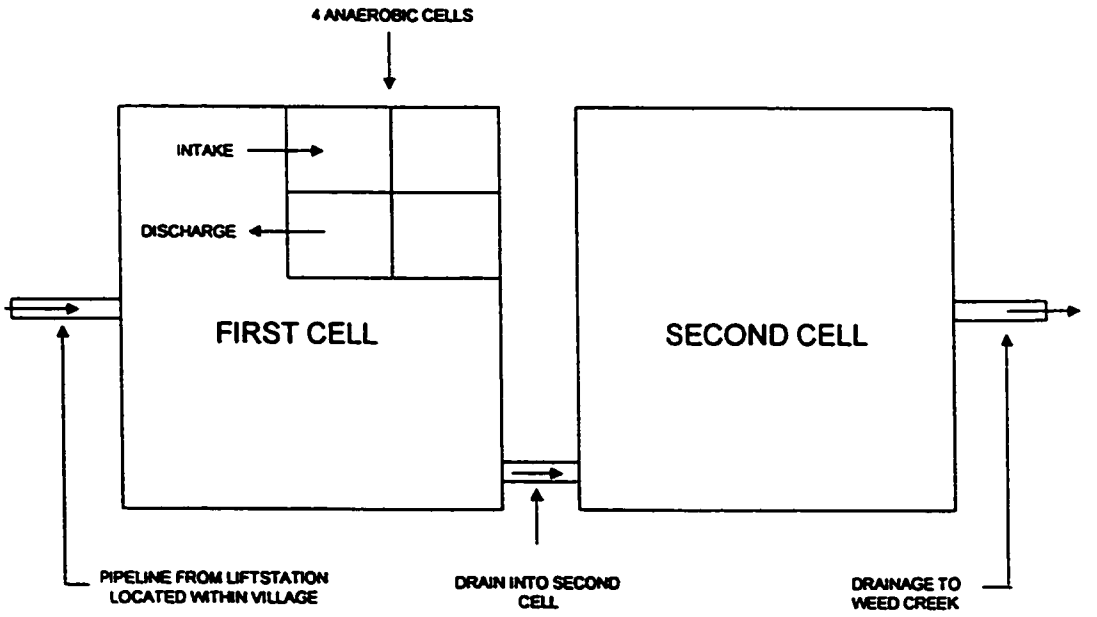
The Sunnybrook STL, identified as star "P" in Figure 3.2, is located in the small village of Sunnybrook, Alberta. It serves a population of 70 people and has a storage cell capacity of 15 470 m^3. It accepts only human waste, all of which is piped to the lagoon via a collection system. At present the lagoon does not have a sludge management practice. The lagoon is permitted to discharge once per year during the period of April 1 to November 30 for a maximum of three weeks. The lagoon discharges into Strawberry Creek, which flows directly into the North Saskatchewan River. The lagoon discharged in 1998 and in 1999, and its effluent was sampled only in 1998 during the study. As for historical discharges, the lagoon discharged in 1997, 1996 and in 1995.

C.9 Thorsby STL

The Thorsby STL, identified as star "O" in Figure 3.2, is located in the village of Thorsby, Alberta. It serves a population of 725 people in the village and its surrounding areas. The treatment system is typical of lagoons in Alberta, it consists of a primary lagoon that has 4 anaerobic cells and one small short-term retention facultative cell that is separated by a berm separates from the larger secondary storage cell. The storage cell has a capacity of 195 000 m^3. The lagoon accepts only human/municipal waste, and does not accept industrial or

agricultural waste. The wastewater is piped to the facility via a sanitary sewer collection system. At present the lagoon has not had to practice sludge management techniques. The lagoon is permitted to discharge once per year during the period of April 1 to November 30 for a maximum of three weeks. The lagoon discharges into Weed Creek, which flows directly into the North Saskatchewan River. The lagoon discharged in 1998 and in 1999, and the effluent was sampled once during the study in 1999. As for historical discharges, the lagoon was discharged in 1997, 1996 and 1995.

THORSBY LAGOON



C.10 Tomahawk (main) STL

The Tomahawk (main) STL, identified as star "J" in Figure 3.2, is located in the town of Tomahawk, Alberta. It serves a population of 130 people in the town and its surrounding areas. The lagoon has a storage capacity of 9 565 m^3 and accepts only human and municipal wastewater. The wastewater is brought to

the lagoon via a pipe collection system. At present the lagoon does not have sludge management practices. The lagoon is permitted to discharge twice per year during the period of March 1 to November 30 each year, for a maximum period of three weeks each time. The lagoon discharges into Tomahawk Creek, which flows directly into the North Saskatchewan River. The lagoon was discharged twice in 1998 and twice in 1999. The lagoon was sampled during all discharges in 1998 and in 1999 during the study (a total of 4 samples). As for historical discharges, the lagoon has discharged twice in 1997, 1996 and 1995.

C.11 Tomahawk (school) STL

The Tomahawk (school) STL, identified as star "K" in Figure 3.2, is located on the property of the school in Tomahawk, Alberta. It has a storage capacity of 6 371 m^3 and serves approximately 100 people only during school hours. The lagoon accepts only human wastes, which are piped directly to the lagoon. At present the lagoon does not have sludge management practices. The lagoon is permitted to discharge once per year during the period of April 1 to November 30 for a period of no more than three weeks. The lagoon discharges into Tomahawk Creek, which flows directly into the North Saskatchewan River. The lagoon was discharged in 1998 and 1999 and the effluent was sampled both times during the study. As for historical discharges, the lagoon discharged in 1997, 1996 and 1995.

C.12 Warburg STL

The Warburg STL, identified as star "N" in Figure 3.2, is located in the town of Warburg, Alberta and it serves a population of approximately 549 people in the town and its surrounding area. The lagoon has a storage cell capacity of 118 608 m^3. The lagoon accepts human waste and wash water from an animal processing plant. All wastewater is piped to the lagoon via a collection system. At present the lagoon does not have a sludge management practice. The lagoon is permitted to discharge once per year during the period of April 1 to November 30 for a maximum of three weeks. The lagoon discharges into Strawberry Creek, which flows directly into the North Saskatchewan River. The lagoon was discharged in 1998 and 1999, and the effluent was sampled both years during the study. As for historical discharges, the lagoon discharged in 1997, 1996 and 1995.

C.13 Winfield STL

The Winfield STL, identified as star "M" in Figure 3.2, is located in the town of Winfield, Alberta and has a storage capacity of 11 250 m^3. The lagoon serves a population of approximately 240 people in the town and surrounding area. It accepts only human and municipal waste, all of which is piped into the lagoon via a collection system. At present the lagoon does not have a sludge management practice. The lagoon is permitted one discharge per year during the period of April 1 to November 30 for a maximum of three weeks. The lagoon discharges into Modeste Creek, which flows directly into the North Saskatchewan River. The lagoon discharged in 1998 and 1999, however it was only sampled 1999

during the study period. As for historical discharges, the lagoon was discharged in 1997, 1996 and 1995.

Appendix D: Water Treatment Plants Descriptions and Layout

D.1 Rocky Mountain House

D.2 Drayton Valley

D.3 Thorsby

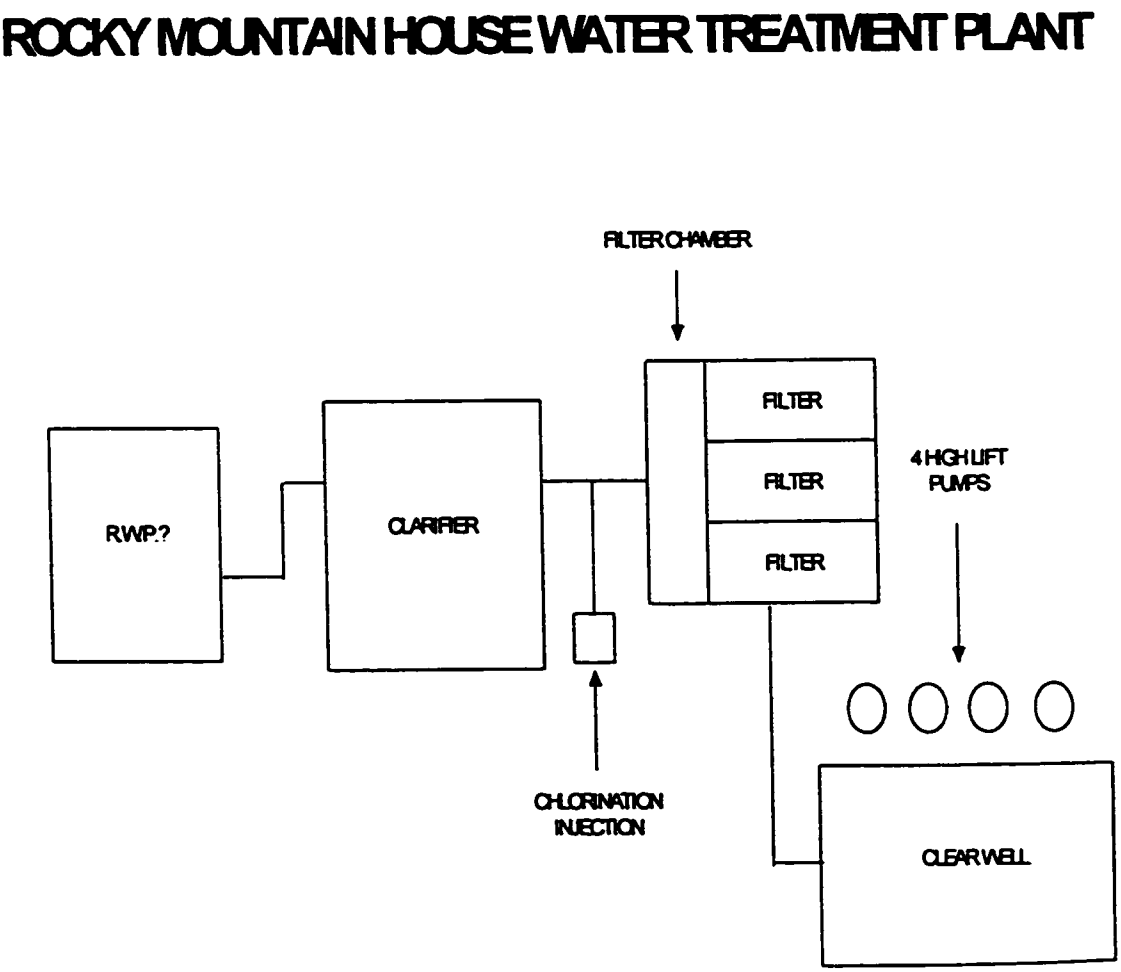
D.4 Devon

D.5 E.L. Smith

D.6 Rossdale

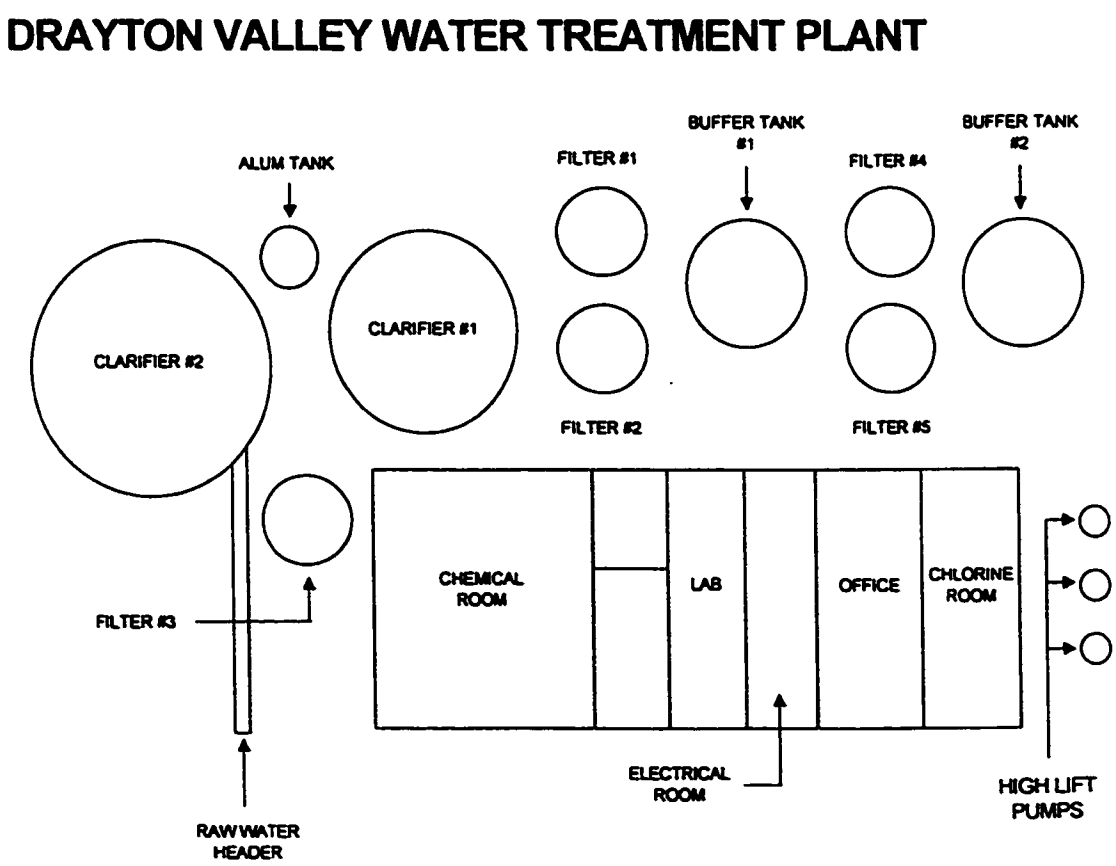
D.1 Rocky Mountain House WTP

The Rocky Mountain House WTP, identified as triangle "30" in Figure 3.2, is located in the town of Rocky Mountain House, Alberta and is used to supply water to approximately 6062 people in the town and its surrounding areas. The treatment processes include a solids contact clarifier, chemical coagulation, sand filtration and gas chlorination. The WTP has a design capacity of 8 400 m^3/day (8.4 ML/day). It was first built in 1985 and has not undergone any expansions or upgrades. The facility receives its water from the North Saskatchewan River



D.2 Drayton Valley WTP

The Drayton Valley WTP, identified as triangle "31" in Figure 3.2, supplies water to approximately 6000 people in the city of Drayton Valley, Alberta and its surrounding areas. It receives its water supply directly from the North Saskatchewan River. Its treatment processes include a two-day retention settling pond, screens, upflow clarifiers and liquid alum and a polymer as a coagulant aid. It uses a dual media (anthracite and sand) gravity filtration system followed by fluoridation and gas chlorination. The WTP has a design capacity of 6.5 ML/day. It was first built in 1972 and was expanded in 1987 to its present capacity.



D.3 Thorsby WTP

The Thorsby WTP, identified as triangle "32" in Figure 3.2, located in the village of Thorsby, Alberta and is used to supply water to approximately 725 people in the village, and its surrounding areas. The treatment processes include flocculation, coagulation, sedimentation, slow sand filtration, liquid chlorination and fluoridation. The WTP has a design capacity of 0.91 ML/day. It was first built in 1954 and underwent an expansion in 1960, the early 1970's and most recently in 1995. The facility receives its water from the North Saskatchewan River via an Esso water withdrawal pipeline.

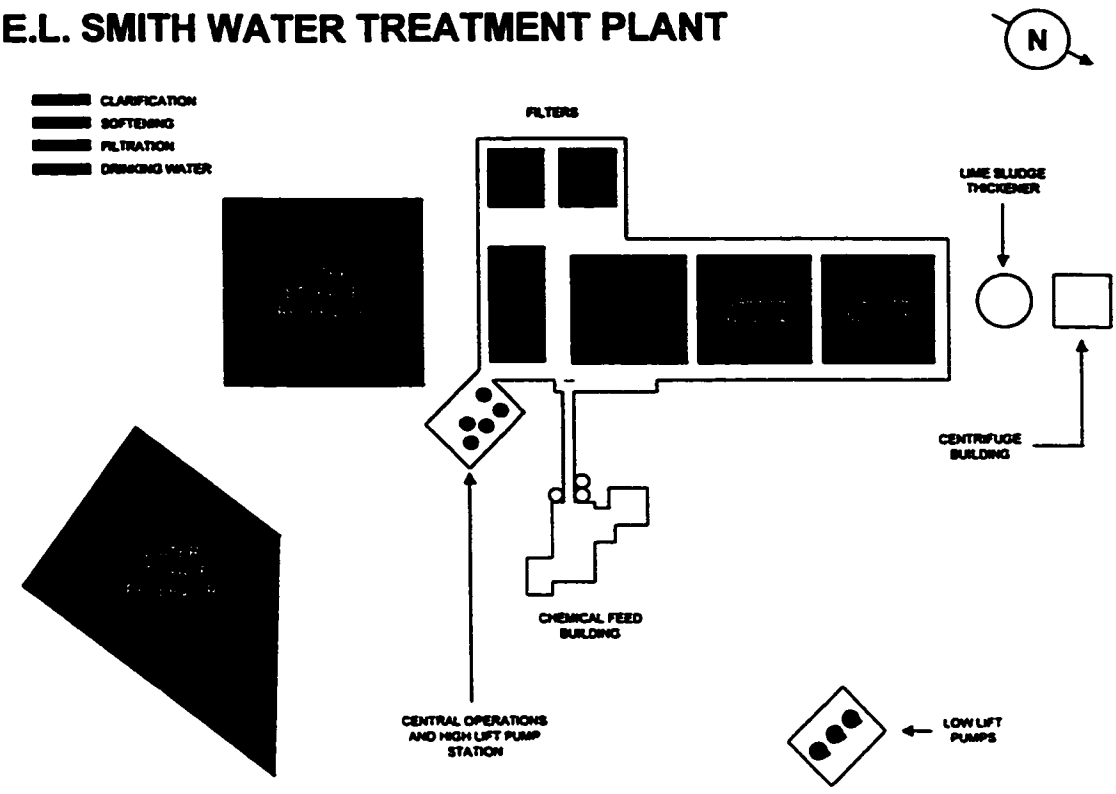
D.4 Devon WTP

The Devon WTP, identified as triangle "33" in Figure 3.2, supplies water to approximately 5000 people in the city of Devon, Alberta and its surrounding areas. The treatment processes include one solids contact reactor type clarifier, 4 rapid sand filters, post gas chlorination and fluoridation. The WTP has a design capacity of 7.2 ML/day. It was first built in 1974, in 1986 and expansion was undertaken to increase the pumps. In 1993 the filter capacity was increased, as was the exiting clarifier capacity with the installation of tube settlers. At present, a second solids contact reactor type clarifier is being built increasing the original design capacity from 3.6 ML/day to 7.2 ML/day.

D.5 E.L. Smith WTP

The E.L. Smith WTP, owned and operated by EPCOR and identified as triangle "34" in Figure 3.2, is also located on the North Saskatchewan River, approximately 15 km upstream of the Rossdale WTP on the western fringes of the City of Edmonton. The facility was originally built in 1976 and was expanded to its current configuration in 1984. The E.L. Smith WTP treats an average of 65 710 ML/year.

The E.L. Smith Facility is currently a single-train facility with a design capacity of 190 ML/day. The coagulation equipment consists of three identical upflow solids-contacting clarifiers. Under normal operating conditions two of the clarifiers are used for alum coagulation, and one is used for lime softening. PAC can be added on demand in order to control taste and odour problems. Disinfection occurs through the use of free-chlorine, followed by the addition of ammonia in order to ensure a chloramine residual in the distribution system. The water is also fluoridated. The effluent is then filtered via dual-media (anthracite and sand) rapid sand filtration before being pumped into 125 ML on-site reservoirs.



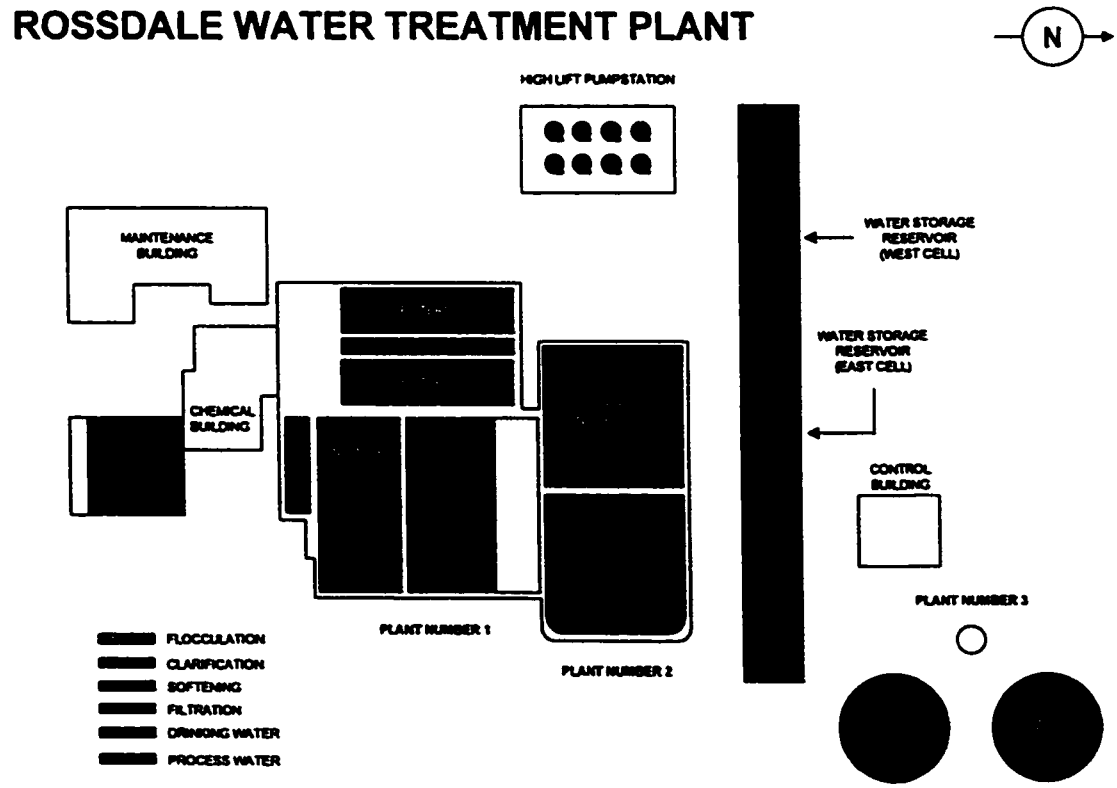
D.6 Rossdale WTP

The Rossdale WTP, owned and operated by EPCOR and identified as triangle "35" in Figure 3.2, is located on the North Saskatchewan River, within the boundaries of the City of Edmonton. The facility was originally constructed in 1946 and was expanded in 1955 to meet the needs of the expanding Edmonton population. The Rossdale treats an average of 55 109 ML/year.

The Rossdale WTP is composed of two independent treatment trains, identified as Plant #1 and Plant #2, which each having a design capacity of 107 ML/day. Each plant consists of one square cross-flow clarifier that is comprised of a rapid-mix chamber, three stages of tapered flocculators, and one sedimentation basin.

Up-flow tube settlers assist in the sedimentation process. Enhanced alum coagulation with an anionic polymer coagulant aid is practiced at the Rossdale WTP. PAC can also be added on demand in order to control severe taste and odour problems, which are especially prevalent during spring runoff.

Lime softening and recarbonated in order to adjust the pH follow the softening process. Free-chlorine and ammonia are used for microbiological reduction (disinfection). The water is then fluoridated, and finally filtered via mono-media (crushed –quartz) rapid sand filtration. Following filtration the water is then pumped into 100 ML on-site reservoirs.



Appendix E: Total Annual Flow (m^3) and Annual Unit Runoff (mm)

E.1 North Saskatchewan River at Edmonton

E.2 Strawberry Creek

E.3 Tomahawk Creek

E.4 Baptiste River

E.5 Nordegg River

E.6 Rose Creek

E.7 Weed Creek

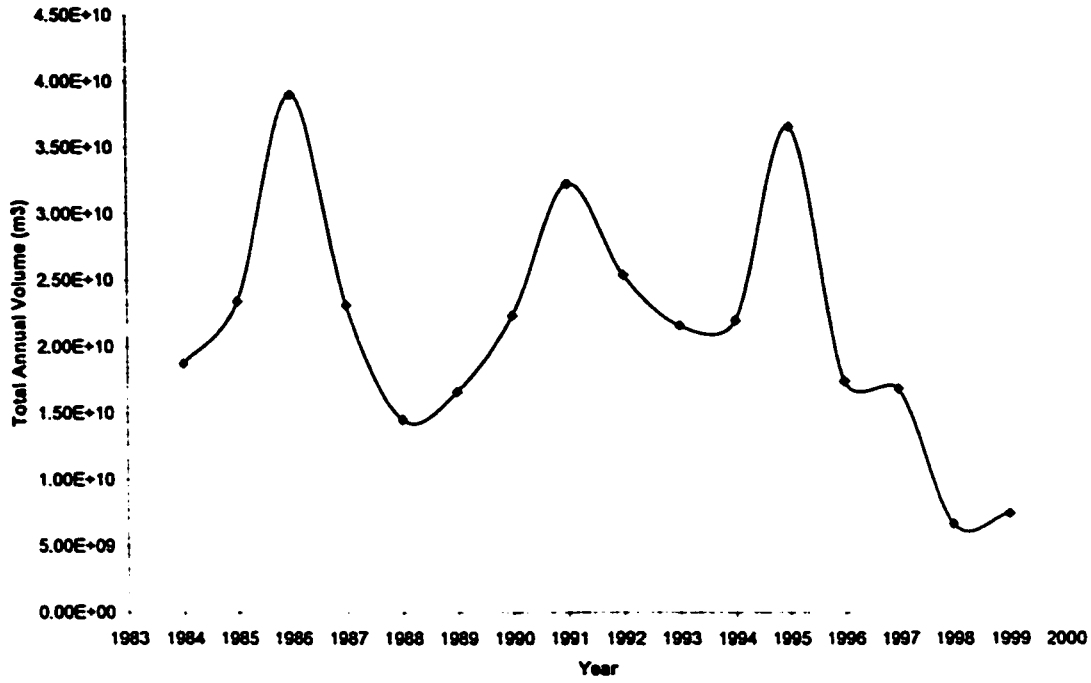
E.8 Mishow Creek

Table E.1 North Saskatchewan River Total Annual Flow (m^3) and Total Annual Unit Runoff (mm)

YEAR	TOTAL VOLUME (m^3)	ANNUAL UNIT RUNOFF (mm)
1984	1.87E+10	66.8
1985	2.34E+10	83.6
1986	3.90E+10	139.2
1987	2.31E+10	82.5
1988	1.45E+10	51.9
1989	1.66E+10	59.3
1990	2.23E+10	79.8
1991	3.23E+10	115.2
1992	2.54E+10	90.6
1993	2.16E+10	77.0
1994	2.20E+10	78.5
1995	3.66E+10	130.6
1996	1.74E+10	62.2
1997	1.69E+10	60.3
1998	6.71E+09	24.0
1999	7.52E+09	26.9

Column 1	*Rank*	*Percent*	*Percentile*
3.9E+10	1	100.00%	100
3.66E+10	2	93.30%	100
3.23E+10	3	86.60%	100
2.54E+10	4	80.00%	100
2.34E+10	5	73.30%	75
2.31E+10	6	66.60%	75
2.23E+10	7	60.00%	75
2.2E+10	8	53.30%	75
2.16E+10	9	46.60%	50
1.87E+10	10	40.00%	50
1.74E+10	11	33.30%	50
1.69E+10	12	26.60%	50
1.66E+10	13	20.00%	25
1.45E+10	14	13.30%	25
7.52E+09	15	6.60%	25
6.71E+09	16	.00%	25

Total Annual Volume (m^3) of the North Saskatchewan River for the Years 1984 to 1999



Total Annual Unit Runoff (mm) of the North Saskatchewan River at Edmonton for the Years 1984 to 1999

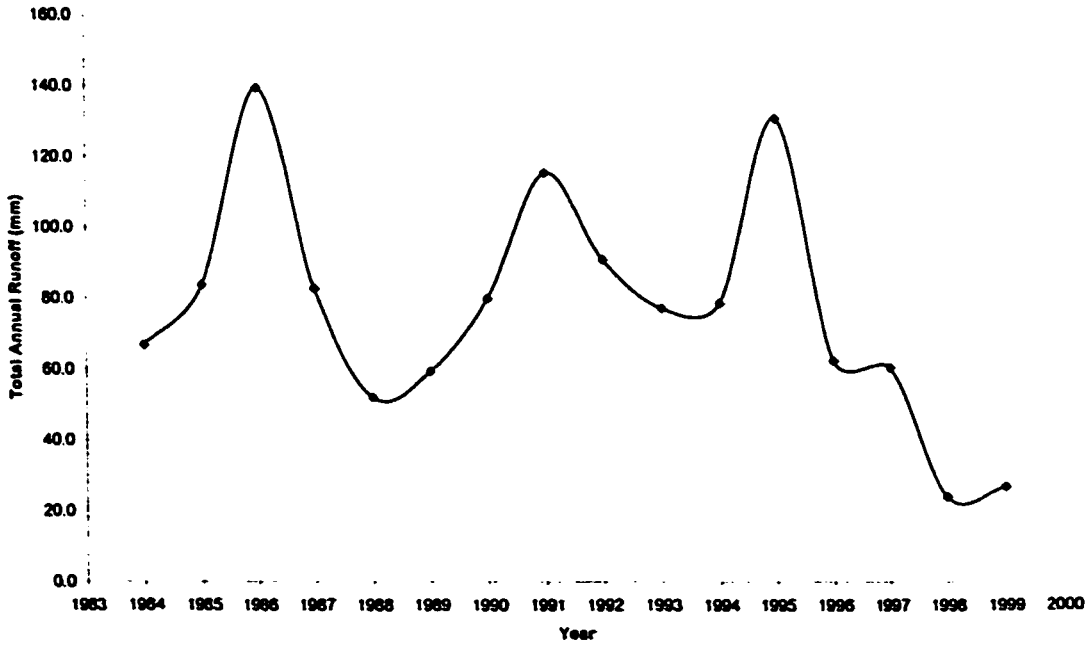
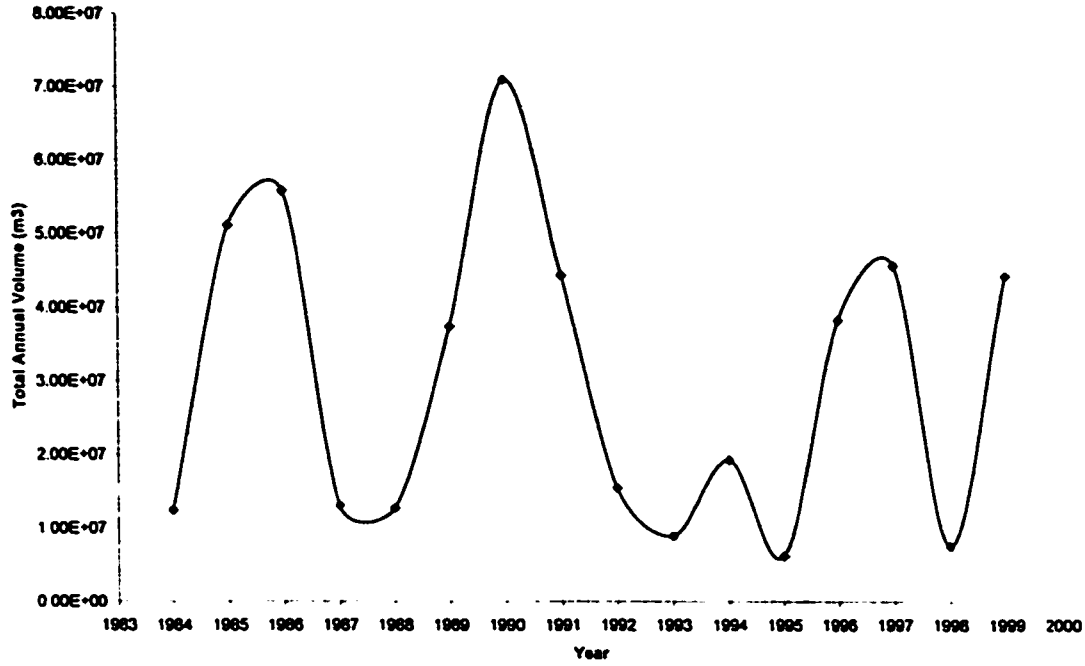


Table E.2 Strawberry Creek Total Annual Flow (m^3) and Total Annual Unit Runoff (mm)

POINT	YEAR	TOTAL ANNUAL VOLUME (m^3)	ANNUAL UNIT RUNOFF (mm)
1	1984	1.25E+07	2.1
2	1985	5.11E+07	8.8
3	1986	5.58E+07	9.6
4	1987	1.31E+07	2.2
5	1988	1.27E+07	2.2
6	1989	3.74E+07	6.4
7	1990	7.09E+07	12.1
8	1991	4.43E+07	7.6
9	1992	1.54E+07	2.6
10	1993	8.96E+06	1.5
11	1994	1.93E+07	3.3
12	1995	6.20E+06	1.1
13	1996	3.82E+07	6.5
14	1997	4.56E+07	7.8
15	1998	7.56E+06	1.3
16	1999	4.42E+07	7.6

Point	*Column1*	*Rank*	*Percent*	*Percentile*
7	7.09E+07	1	100.00%	100
3	5.58E+07	2	93.30%	100
2	5.11E+07	3	86.60%	100
14	4.56E+07	4	80.00%	100
8	4.43E+07	5	73.30%	75
16	4.42E+07	6	66.60%	75
13	3.82E+07	7	60.00%	75
6	3.74E+07	8	53.30%	75
11	1.93E+07	9	46.60%	50
9	1.54E+07	10	40.00%	50
4	1.31E+07	11	33.30%	50
5	1.27E+07	12	26.60%	50
1	1.25E+07	13	20.00%	25
10	8.96E+06	14	13.30%	25
15	7.56E+06	15	6.60%	25
12	6.20E+06	16	.00%	25

Distribution of Total Annual Volume (m^3) of Strawberry Creek Over the Years 1984 to 1999



Total Annual Unit Runoff (mm) for Strawberry Creek 1984-1999

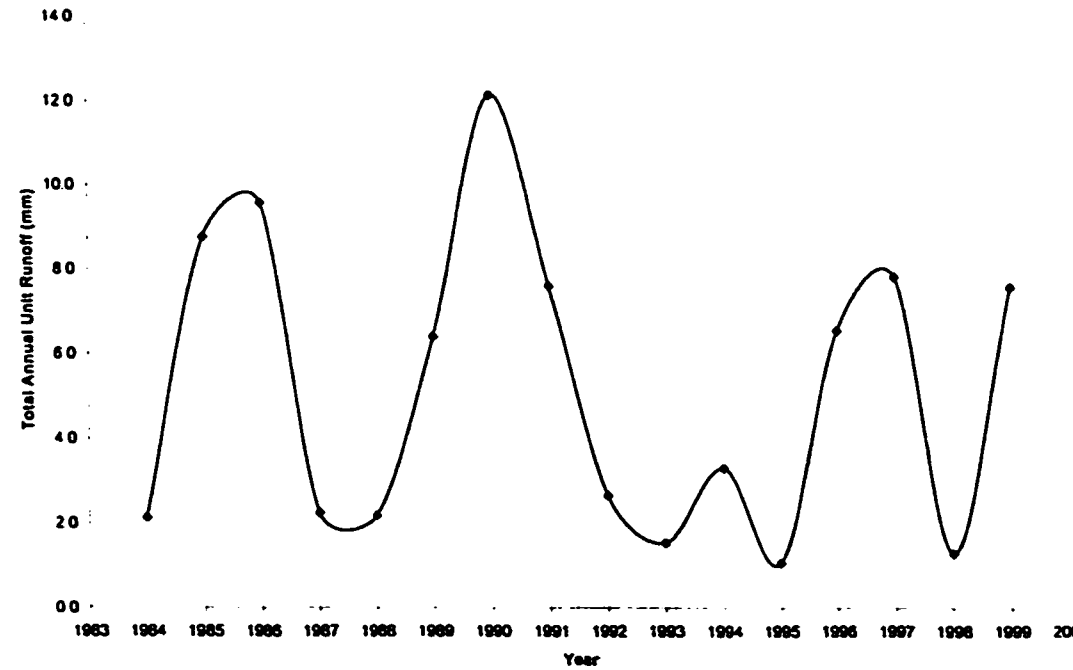
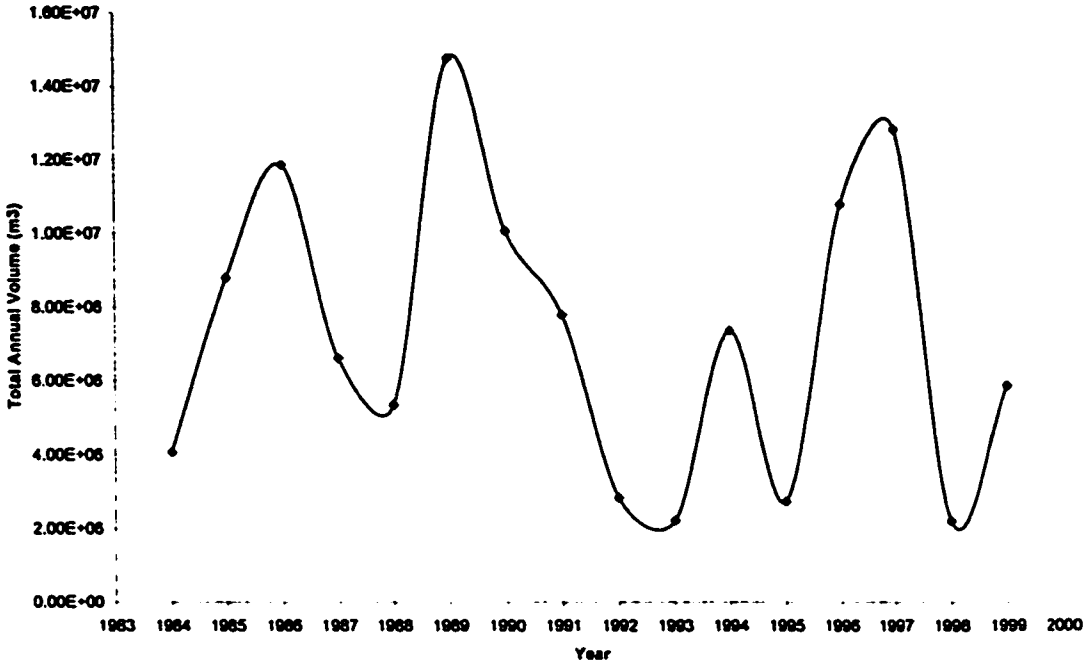


Table E.3 Tomahawk Creek Total Annual Flow (m^3) and Total Annual Unit Runoff (mm)

POINT	YEAR	TOTAL ANNUAL VOLUME (m^3)	ANNUAL UNIT RUNOFF (mm)
1	1984	4.08E+06	3.9
2	1985	8.81E+06	8.4
3	1986	1.19E+07	11.3
4	1987	6.61E+06	6.3
5	1988	5.36E+06	5.1
6	1989	1.48E+07	14.1
7	1990	1.01E+07	9.6
8	1991	7.79E+06	7.4
9	1992	2.84E+06	2.7
10	1993	2.23E+06	2.1
11	1994	7.37E+06	7.0
12	1995	2.74E+06	2.6
13	1996	1.08E+07	10.3
14	1997	1.28E+07	12.2
15	1998	2.21E+06	2.1
16	1999	5.86E+06	5.6

Point	*Column1*	*Rank*	*Percent*	*Percentile*
6	1.48E+07	1	100.00%	100
14	1.28E+07	2	93.75%	100
3	1.19E+07	3	87.50%	100
13	1.08E+07	4	81.25%	100
7	1.01E+07	5	75.00%	75
2	8.81E+06	6	68.75%	75
8	7.79E+06	7	62.50%	75
11	7.37E+06	8	56.25%	75
4	6.61E+06	9	50.00%	50
16	5.86E+06	10	43.75%	50
5	5.36E+06	11	37.50%	50
1	4.08E+06	12	31.25%	50
9	2.84E+06	13	25.00%	25
12	2.74E+06	14	18.75%	25
10	2.23E+06	15	12.50%	25
15	2.21E+06	16	6.25%	25

Distribution of Total Annual Volume (m^3) of Tomahawk Creek Over the Years 1984 to 1998



Total Annual Unit Runoff (mm) for Tomahawk Creek for the Years 1984 to 1998

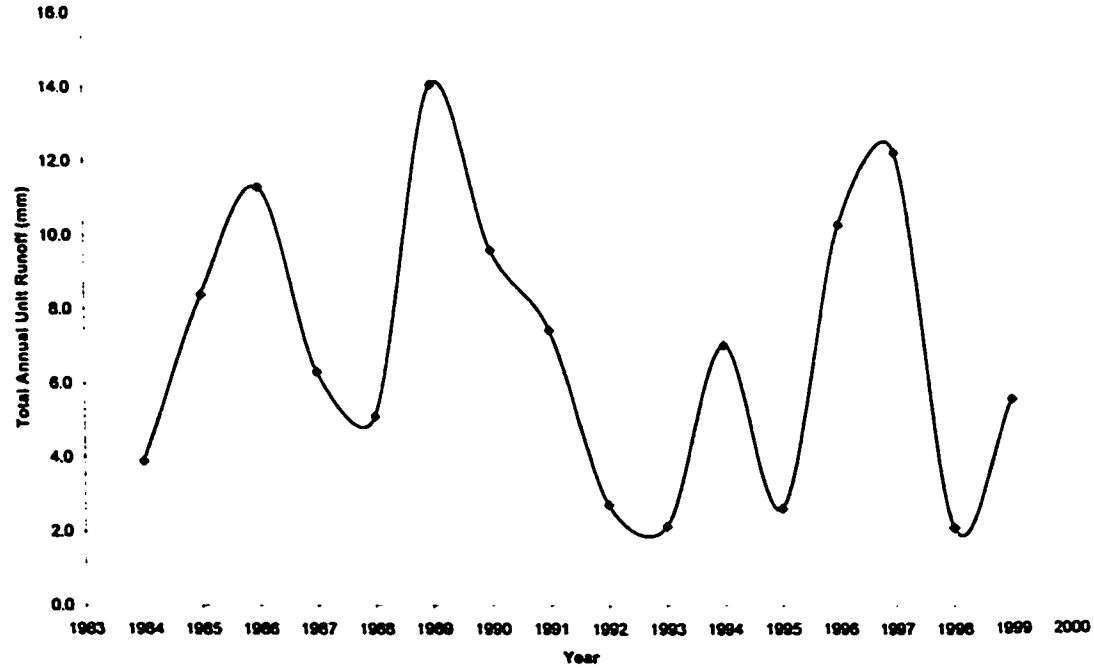
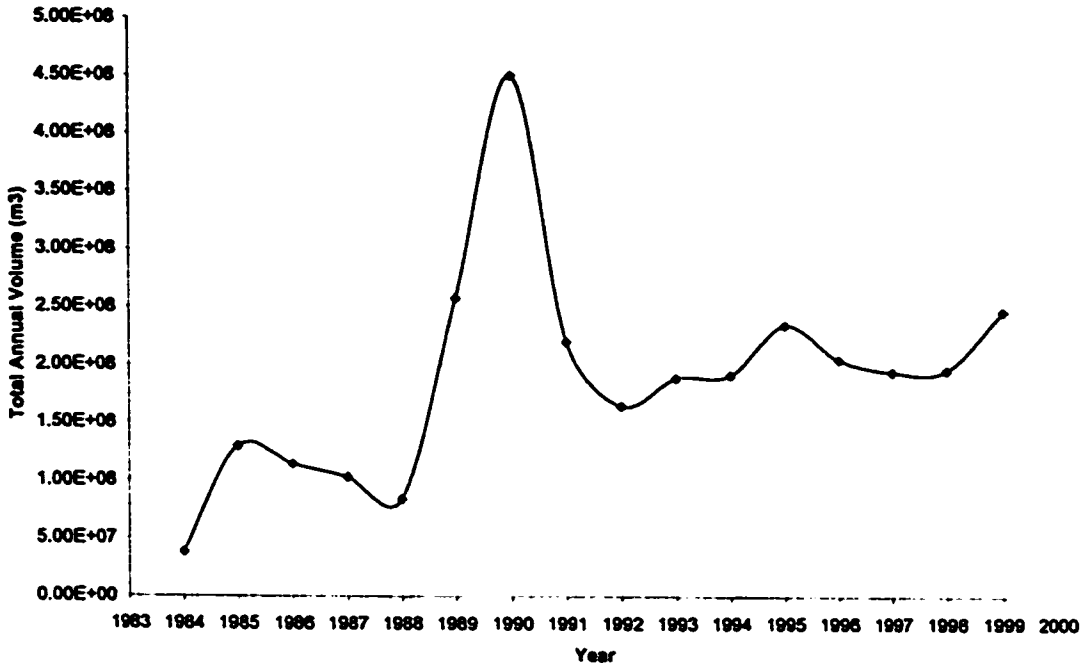


Table E.4 Baptiste River Total Annual Flow (m^3) and Total Annual Unit Runoff

Point	Year	Total Annual Volume (m^3)	Annual Unit Runoff (mm)
1	1984	3.83E+07	2.8
2	1985	1.30E+08	9.6
3	1986	1.15E+08	8.5
4	1987	1.03E+08	7.6
5	1988	8.43E+07	6.2
6	1989	2.58E+08	19.1
7	1990	4.50E+08	33.3
8	1991	2.20E+08	16.3
9	1992	1.64E+08	12.2
10	1993	1.89E+08	14.0
11	1994	1.92E+08	14.2
12	1995	2.34E+08	17.4
13	1996	2.05E+08	15.2
14	1997	1.95E+08	14.4
15	1998	1.96E+08	14.5
16	1999	2.46E+08	18.2

Point	*Column1*	*Rank*	*Percent*	*Percentile*
7	4.50E+08	1	1.00%	100
6	2.58E+08	2	93.75%	100
16	2.46E+08	3	87.50%	100
12	2.34E+08	4	81.25%	100
8	2.20E+08	5	75.00%	75
13	2.05E+08	6	68.75%	75
15	1.96E+08	7	62.50%	75
14	1.95E+08	8	56.25%	75
11	1.92E+08	9	50.00%	50
10	1.89E+08	10	43.75%	50
9	1.64E+08	11	37.50%	50
2	1.30E+08	12	31.25%	50
3	1.15E+08	13	25.00%	25
4	1.03E+08	14	18.75%	25
5	8.43E+07	15	12.50%	25
1	3.83E+07	16	6.25%	25

Total Annual Volume (m^3) of the Baptiste River from 1984 to 1999



Total Annual Unit Runoff (mm) of the Baptiste River for the Years 1984 to 1999

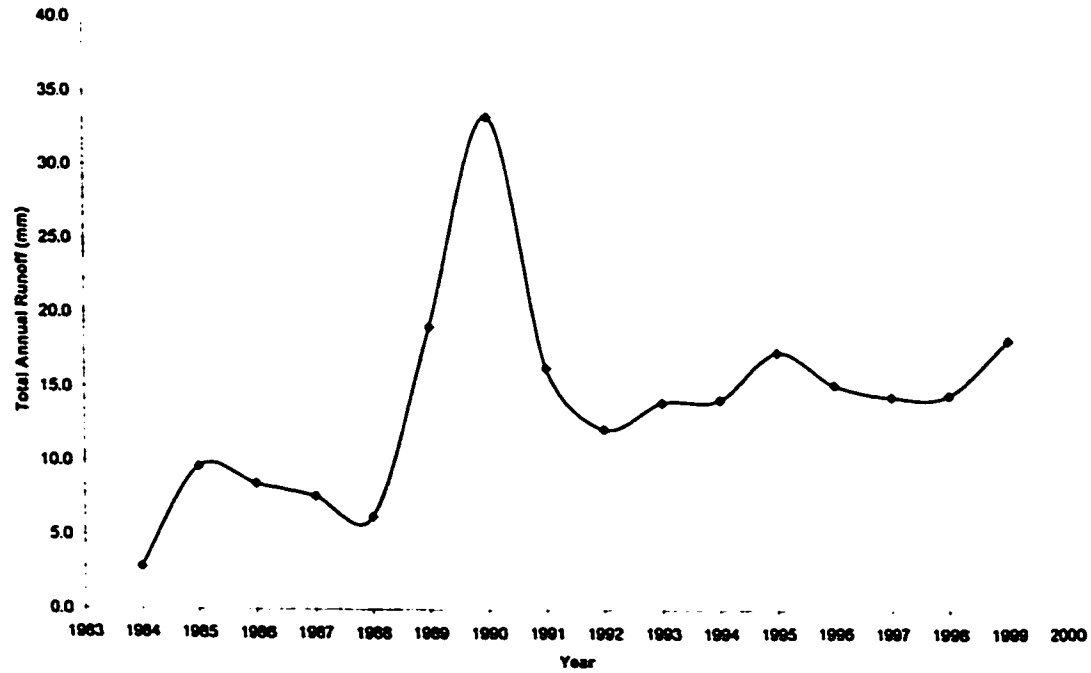
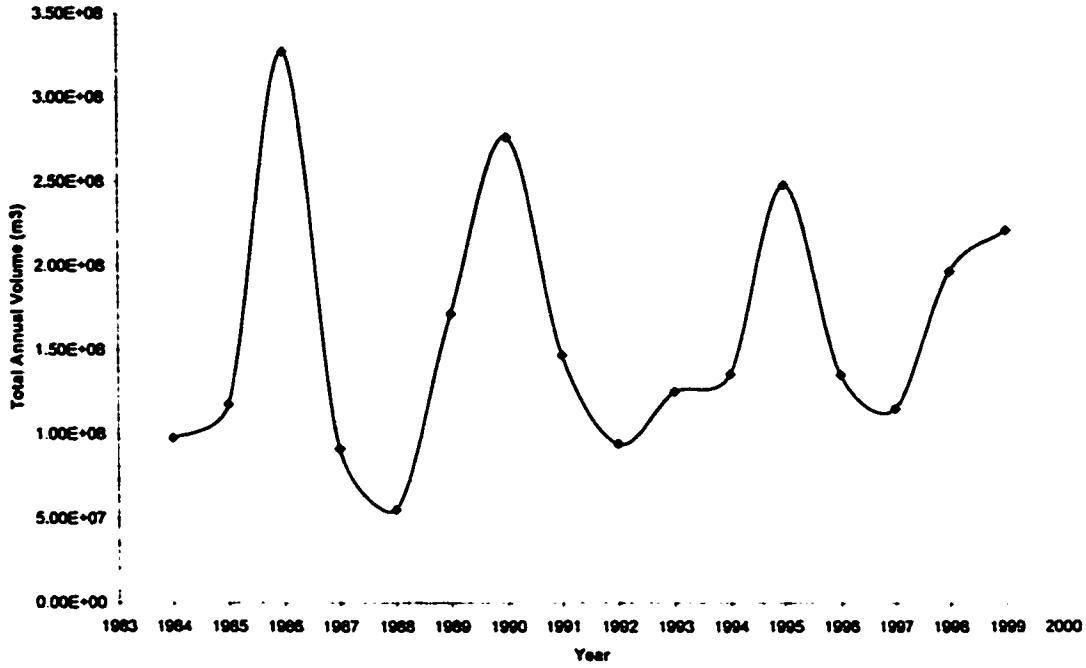


Table E.5 Nordegg River Total Annual Flow (m^3) and Total Annual Unit Runoff (mm)

Point	Year	Total Annual Volume (m^3)	Annual Unit Runoff (mm)
1	1999	2.21E+08	25.3
2	1998	1.97E+08	22.5
3	1997	1.15E+08	13.2
4	1996	1.35E+08	15.5
5	1995	2.48E+08	28.3
6	1994	1.36E+08	15.5
7	1993	1.25E+08	14.3
8	1992	9.44E+07	10.8
9	1991	1.47E+08	16.8
10	1990	2.76E+08	31.6
11	1989	1.72E+08	19.6
12	1988	5.52E+07	6.3
13	1987	9.15E+07	10.5
14	1986	3.27E+08	37.4
15	1985	1.18E+08	13.5
16	1984	9.80E+07	11.2

Point	*Column1*	*Rank*	*Percent*	*Percentile*
14	3.27E+08	1	100.00%	100.00%
10	2.76E+08	2	93.75%	100.00%
5	2.48E+08	3	87.50%	100.00%
1	2.21E+08	4	81.25%	100.00%
2	1.97E+08	5	75.00%	75.00%
11	1.72E+08	5	68.75%	75.00%
9	1.47E+08	6	62.50%	75.00%
6	1.36E+08	7	56.25%	75.00%
4	1.35E+08	8	50.00%	50.00%
7	1.25E+08	9	43.75%	50.00%
15	1.18E+08	10	37.50%	50.00%
3	1.15E+08	11	31.25%	50.00%
16	97964294	12	25.00%	25.00%
8	94386125	13	18.75%	25.00%
13	91487059	14	12.50%	25.00%
12	55248480	15	6.25%	25%

Total Annual Volume (m^3) of the Nordegg River for the Years 1984 to1998



Total Annual Runoff (mm) of the Nordegg River for the Years 1984 to 1999

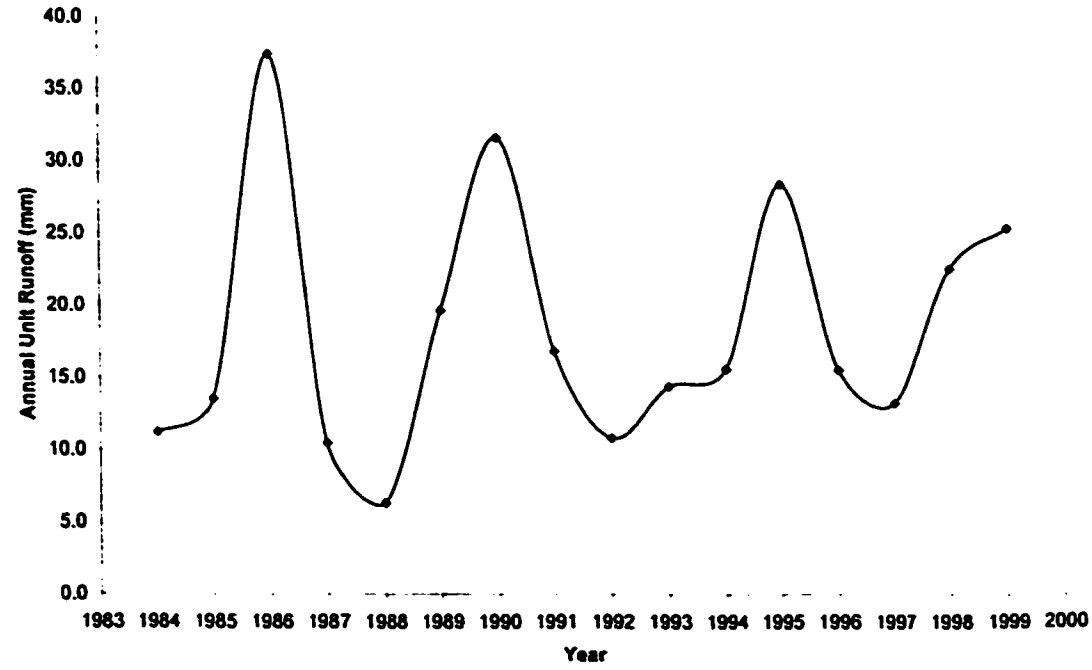
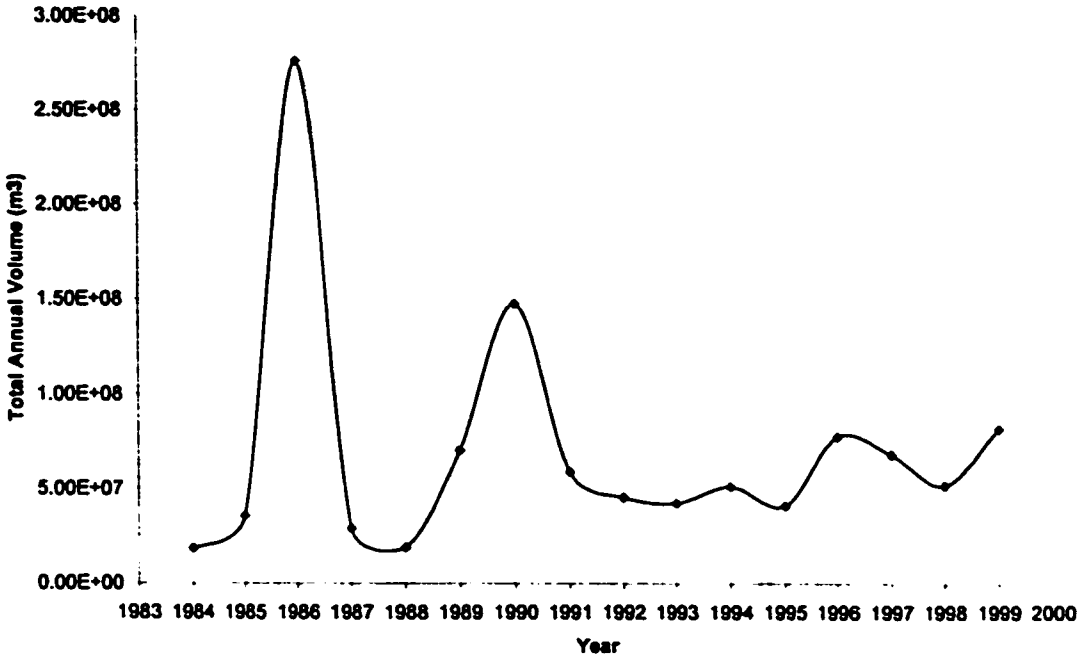


Table E.6 Rose Creek Total Annual Flow (m^3) and Total Annual Unit Runoff (mm)

Point	YEAR	TOTAL ANNUAL VOLUME (m^3)	ANNUAL UNIT RUNOFF (mm)
1	1984	1.83E+07	3.3
2	1985	3.57E+07	6.5
3	1986	2.76E+08	50.1
4	1987	2.90E+07	5.3
5	1988	1.89E+07	3.4
6	1989	7.05E+07	12.8
7	1990	1.48E+08	26.8
8	1991	5.89E+07	10.7
9	1992	4.55E+07	8.3
10	1993	4.24E+07	7.7
11	1994	5.12E+07	9.3
12	1995	4.09E+07	7.4
13	1996	7.77E+07	14.1
14	1997	6.81E+07	12.4
15	1998	5.20E+07	9.4
16	1999	8.18E+07	14.8

Point	*Column1*	*Rank*	*Percent*	*Percentile*
3	2.76E+08	1	100.00%	100
7	1.48E+08	2	93.30%	100
16	8.18E+07	3	86.60%	100
13	7.77E+07	4	80.00%	100
6	7.05E+07	5	73.30%	75
14	6.81E+07	6	66.60%	75
8	5.89E+07	7	60.00%	75
15	5.20E+07	8	53.30%	75
11	5.12E+07	9	46.60%	50
9	4.55E+07	10	40.00%	50
10	4.24E+07	11	33.30%	50
12	4.09E+07	12	26.60%	50
2	3.57E+07	13	20.00%	25
4	2.90E+07	14	13.30%	25
5	1.89E+07	15	6.60%	25
1	1.83E+07	16	.00%	25

Total Annual Volume (m^3) of Rose Creek for the Years 1984 to 1999



Total Annual Unit Runoff (mm) for Rose Creek for the Years 1984 to 1999

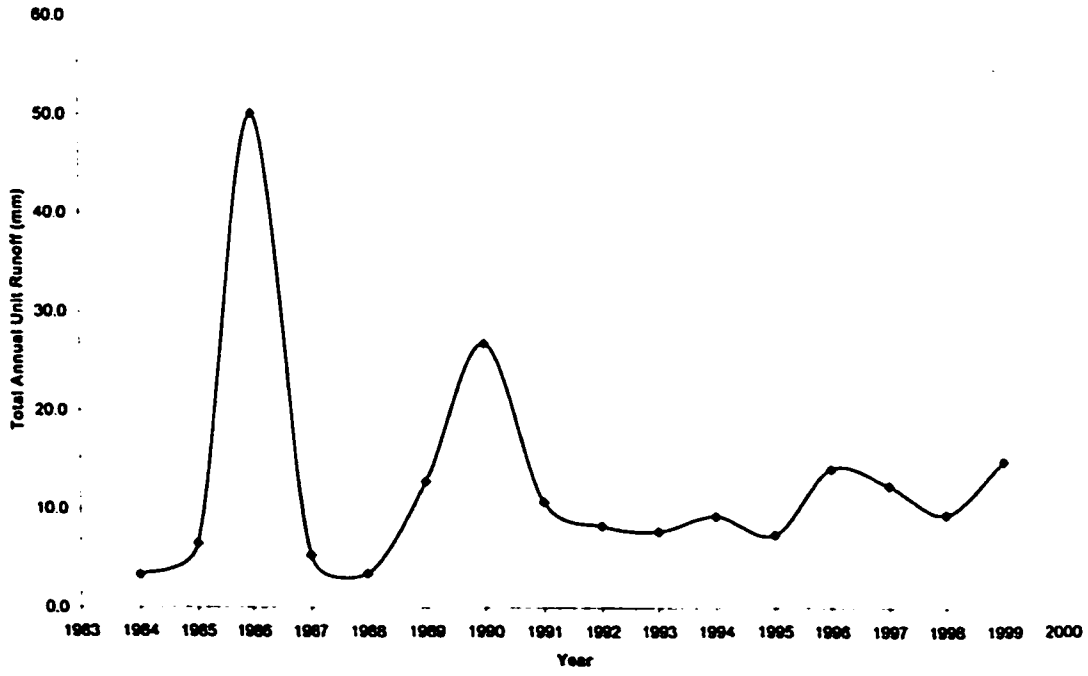
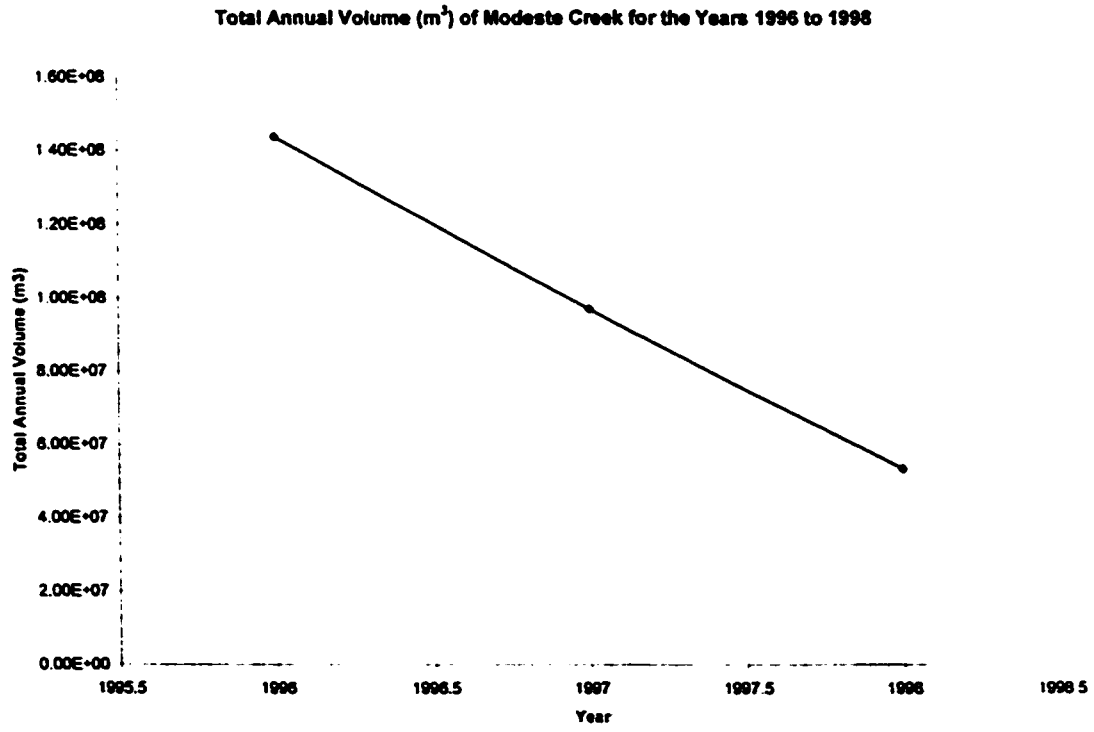
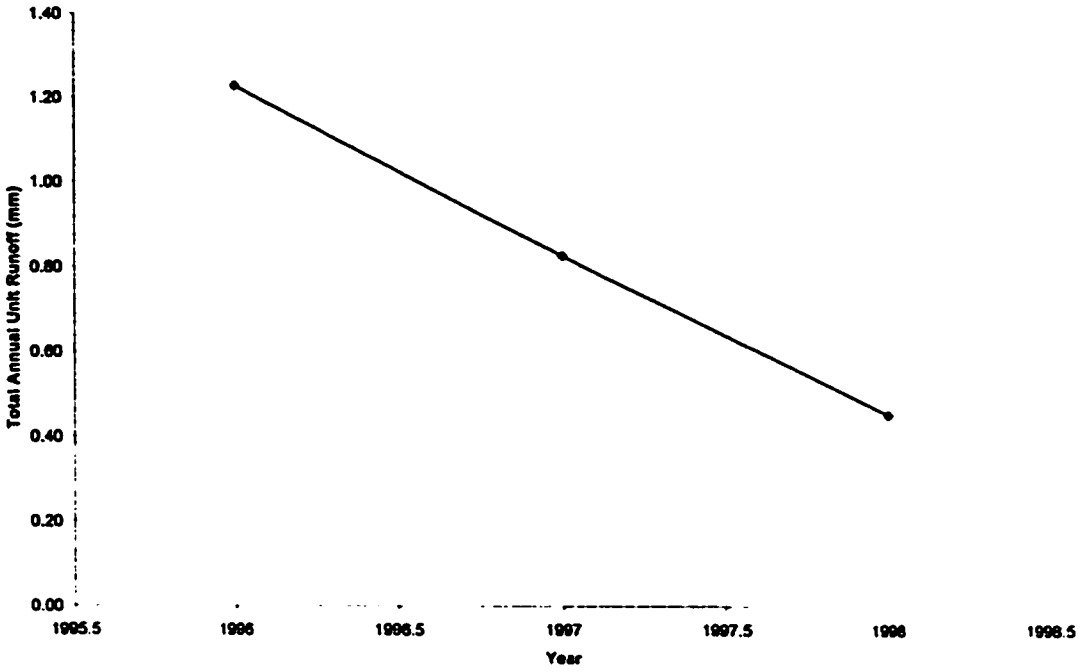


Table E.7 Modeste Creek Total Annual Flow (m^3) and Total Annual Unit Runoff (mm)

Point	Year	Total Annual Volume (m^3)	Annual Unit Runoff (mm)
4	1999	not available yet	
3	1998	5.31E+07	0.45
2	1997	9.69E+07	0.83
1	1996	1.44E+08	1.23

Point	*Column 1*	*Rank*	*Percent*
1	1996	1.44E+08	100
2	1997	9.69E+07	67
3	1998	5.31E+07	33




Total Annual Unit Runoff (mm) of Modesto Creek for the Years 1996 to 1998
Total Annual Unit Runoff (mm)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1995.5
1996
1996.5
1997
1997.5
1998
1998.5
Year

Appendix F

F.1 1998 Longitudinal Survey Spring Runoff Concentration Data

F.2 1998 Longitudinal Survey Summer Rainstorm Concentration Data

F.3 1998 Longitudinal Survey Fall Low-Flow Concentration Data

F.4 1999 Longitudinal Survey Spring Runoff Concentration Data

Table F.1 1998 Spring Runoff Longitudinal Survey Sampling Results

SITE	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. cysts/100L	Turbidity NTU*	Fecal Coliform cfu/100 mL	*Escherichia coli* cfu/100 mL
Wildlife (0 to 0.39 animals/ha)							
Prentice Creek	8-Apr-98	0.326	110	550	13.1	5	5
Baptiste River	21-Apr-98	6.63	230	690	11	5	5
Nordegg River	14-Apr-98	4.94	5	21	2.31	5	5
Sand Creek	8-Apr-98	0.06	67	67	16.3	5	5
Medium Beef Cattle (0.4 to 0.85 animals/ha)							
Shoal Lake Creek	31-Mar-98	0.152	470	160	26.4	5	5
Chicken Creek	29-Mar-98	0.296	2100	33	9.2	2	5
Canyon Creek	28-Mar-98	0.258	24000	14		20	40
Big Beaver Creek	1-Apr-98	0.072	1000	110	5	5	5
Big Beaver Creek	27-Mar-98	0.182				80	80
Rose Creek	28-Mar-98	0.294	3300	270		5	5
Washout Creek	26-Mar-98	0.703	24000	680		30	30
620 Creek	26-Mar-98	0.231	17000	58		100	100
Violet Grove Creek	25-Mar-98	0.394	99000	740	90.8	20	20
Modeste Creek	24-Mar-98	2.01	8100	240		20	20
High Beef Cattle (0.9 to 1.0 animals/ha)							
Mishow Creek	24-Mar-98	0.222	3700	980		10	5
Tomahawk Creek	25-Mar-98	0.132	13000	110	32.6	40	40
Wabamun Creek	27-Mar-98	0.145	4900	520		20	20

Continued on Next Page

SITE	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. cysts/100L	Turbidity NTU*	Fecal Coliform cfu/100 mL	*Escherichia coli* cfu/100 mL
High Agriculture (1.1 to 1.5 animals/ha)							
Strawberry Creek	22-Mar-98	0.5	16000	1100	30.5	40	57
Strawberry Creek	2-Apr-98	3.898	280	970	18.4	57	40
Weed Creek	24-Mar-98	0.517	2500	980		5	5
Conjuring Creek	25-Mar-98	0.342	900	500	54.2	10	10
Graminia Creek	15-Apr-98	0.022	390	85	12	5	5

Table F.2 Summer Rainstorm Event Longitudinal Survey Sampling Results 1998

SITE	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. cysts/100L	Turbidity NTU*	Fecal Coliform cfu/100 mL	*Escherichia coli* cfu/100 mL
Wildlife (0 to 0.39 animals/ha)							
Prentice Creek	28-Jun-98	1.26	980	1500	50.7	120	60
Baptiste River	30-Jun-98	154	25000	*8300*	590	110	100
Nordegg River	05-May-98	3.8	21	10	2.7	5	5
Nordegg River	30-Jun-98	144	*4100*	*4100*	1080	90	70
Sand Creek	30-Jun-98	4.95	*700*	*700*	88.3	50	50
Medium Beef Cattle(0.4 to 0.85 animals/ha)							
Shoal Lake Creek	28-Jun-98	0.062	2800	940	379	63000	47000
Chicken Creek	28-Jun-98	0.428	810	270	84.2	2700	270
Canyon Creek	28-Jun-98	0.225	4700	420	23.3	2700	1800
Big Beaver Creek	28-Jun-98	0.363	400	80	4.34	60	30

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SITE	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. cysts/100L	Turbidity NTU*	Fecal Coliform cfu/100 mL	*Escherichia coli* cfu/100 mL
Rose Creek	29-Jun-98	46.8	5200	*1700*	789	4000	3000
Washout Creek	29-Jun-98	2.26	6400	530	124	500	300
620 Creek	29-Jun-98	0.083	1600	53	24.2	720	510
Violet Grove Creek	29-Jun-98	0.086	670	800	32	670	670
Modeste Creek	28-Jun-98	0.779	1100	83	17.2		
Modeste Creek	30-Jun-98	15	2700	2700	545	110	1100
High Beef Cattle (0.9 to 1.0 animals/ha)							
Tomahawk Creek	28-Jun-98	1	7500	2500	365	310	280
Mishow Creek	28-Jun-98	0.846	620	940	172	5900	5900
Wabamun Creek	28-Jun-98	0.239	88	88	11	690	690
High Agriculture (1.1 to 1.5 animals/ha)							
Strawberry Creek	30-Jun-98	4.9	2000	2000	290	710	640
Weed Creek	28-Jun-98		250	120	21.3	680	570
Weed Creek	29-Jun-98	5.09	*1900*	1900	280	1400	1300
Conjuring Creek	28-Jun-98					1500	1200
Conjuring Creek	02-Jul-98	2.19	*650*	650	132	230	170
Conjuring Creek	07-Jul-98	5.25	6400	4800	283	220	200

Table F.3 Fall Low Flow Longitudinal Survey Sampling Results, 1998

SITE	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. cysts/100L	Turbidity NTU*	Fecal Coliform cfu/100 mL	*Escherichia coli* cfu/100 mL
Wildlife (0 to 0.39 animals/ha)							
Baptiste River (#18)	16-Sep-98		17	180	1.6		
Baptiste River (#20)	15-Sep-98		83	220	1.04		
Nordegg River	16-Sep-98		8	180	0.9		
Medium Beef Cattle (0.4 to 0.85 animals/ha)							
Rose Creek	17-Sep-98		*3*	12	8.2		
Washout Creek	17-Sep-98		*8.5*	83	5.6		
Modeste Creek	10-Sep-98		220	480	10.3		
High Beef Cattle (0.9 to 1.0 animals/ha)							
Mishow Creek	03-Sep-98		450	61	4.3		
Tomahawk Creek	03-Sep-98		400	*100*	42		
High Agriculture (1.1 to 1.5 animals/ha)							
Strawberry Creek	02-Sep-98		450	1400	3		
Conjuring Creek	10-Sep-98		440	440	4.2		

Table F.4 Spring Runoff Longitudinal Survey Sampling Results, 1999

SITE	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. *cysts/100L*	Turbidity NTU*	Fecal Coliform cfu/100 mL	*Escherichia coli* cfu/100 mL
Wildlife (0 to 0.39 animals/ha)							
Prentice Creek	16-Apr-99	0.25	50	200	4.12	10	10
Baptiste River (#20)	27-Apr-99	nd	260	190	3.8	30	30
Baptiste River (#18)	27-Apr-99	17.1	180	180	22	10	5
Nordegg River	16-Apr-99	3.82	170	50	1.99	5	5
Sand Creek	30-Apr-99	0.505	*160*	160	8.4	5	5
Medium Beef Cattle (0.4 to 0.85 animals/ha)							
Shoal Lake Creek	14-Apr-99	1.74	22000	11000	680	40	30
Chicken Creek	10-Apr-99	0.577	100	200	22.3	5	5
Canyon Creek	10-Apr-99	0.254	50	*50*	1.9	20	5
Big Beaver Creek	15-Apr-99	0.102	25	8	2.76	10	10
Rose Creek	15-Apr-99		660	330	23.9	10	10
Washout Creek	21-Apr-99	1.39	*150*	150	15	10	10
620 Creek	14-Apr-99	1.47	2100	2100	63.5	30	30
Violet Grove Creek	14-Apr-99	1.71				110	90
Violet Grove Creek	19-Apr-99	1.07	*1100*	*1100*	110	50	50
Modeste Creek	13-Apr-99		13000	*13000*	1159	100	90
High Beef Cattle (0.9 to 1.0 animals/ha)							
Mishow Creek	13-Apr-99	15.4	8700	*8800*	368	100	100
Tomahawk Creek	12-Apr-99	6.75	7300	*2400*	168	150	150
Tomahawk Creek	15-Apr-99	9.59	*2100*	2100	240	54	54
Wabamun Creek	16-Apr-99	0.867	250	*250*	46	5	5

Continued on Next Page

SITE	Date	Flow m^3/s	*Cryptosporidium* spp. oocysts/100L	*Giardia* spp. *cysts/100L*	Turbidity NTU*	Fecal Coliform cfu/100 mL	*Escherichia coli* cfu/100 mL
High Agriculture (1.1 to 1.5 animals/ha)							
Strawberry Creek	13-Apr-99	43.8	18000	18000	2000	200	100
Strawberry Creek	16-Apr-99	12.8	*1700*	1700	270	30	30
Weed Creek	11-Apr-99	13.1	6200	*1600*	460	140	140
Conjuring Creek	10-Apr-99	8.86	*16000*	*16000*	722	40	40
Graminia Creek	14-Apr-99	1.52	2900	1400	106	30	10

Italicized numbers are values that were below detection limit for Cryptosporidium spp. *and Giardia* spp. *and are reported as full detection limit (15.8% (24/152) samples were below detection limit for 1998 and 1999 longitudinal survey samples).* Highlighted numbers are values that were below detection limit for Fecal coliform and *Escherichia coli* and are reported as ½ detection limit (25% (35/140) samples were below detection limit for 1998 and 1999 longitudinal survey samples)

Appendix G: Sewage Effluent Data

G.1 North Saskatchewan River Basin Wastewater Treatment Plant Effluent Data, 1998-1999

G.2 North Saskatchewan River Basin Sewage Lagoon Effluent Data, 1998-1999

G.3 North Saskatchewan River Basin Sewage Lagoon Discharge History 1995-1999

Table G.1 North Saskatchewan River Basin Wastewater Treatment Plant Effluent Data 1998-1999

SITE	Date	*Cryptosporidium* spp. # cysts/100L*	*Giardia* spp. # cysts/ 100L	Turbidity (NTU)	Fecal coliform (cfu/100mL)	*Escherichia coli* (cfu/100mL)	TSS (mg/L)	Colour (TCU)
Rocky Mountain House WWTP	14-Apr-98	*380*	2600	8.12	80	80	11	37
	20-Jul-98	580	1800	15.3	30	30		
	24-Sep-98	*250*	*250*	5.3	36	10		
	29-Oct-98	190	750	4.2	250	210		
	28-Jan-99	3800	24000	14.85	1E+06	1E+06		
	17-Mar-99	1800	42000	25.7	150000	150000		
	13-May-99	1800	4600	20.8	82	66	77	60
	14-Jul-99	2200	4500	31.5	540	380	63	100
	8-Sep-99	2700	330	5.6	60	50		
	24-Nov-99	*1500*	7500	23.5	1900	870		
Drayton Valley WWTP	7-Apr-98	880	7000	11	30	5	15	32
	20-Jul-98	*310*	310	5.3	36	36		
	22-Sep-98	*400*	*400*	2.4	10	5		
	03-Nov-98	160	320	4.57	30	20		
	26-Jan-99	*880*	27000	6.34	600	470		
	16-Mar-99	160	25000	9.06	27	27	7	25
	11-May-99	*830*	*830*	7.36	50	50	18	40
	7-Jul-99	*100*	100	5	5	5	7	25
	31-Aug-99	170	420	4.55	10	5		
	25-Nov-99	1200	18000	16.3	20	20		

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SITE	Date	*Cryptosporidium* spp. # cysts/100L*	*Giardia* spp. # cysts/ 100L	Turbidity (NTU)	Fecal coliform (cfu/100ML)	*Escherichia coli* (cfu/100mL)	TSS (mg/L)	Colour (TCU)
Devon WWTP	15-Apr-98	2000	16000	5.9	5	5	8	26
	21-Jul-98	250	16000	3.9	5	5		
	23-Sep-98	2000	48000	6.7	5	5		
	05-Nov-98	*620*	44000	10.7	91	30		
	01-Feb-99	*180000*	900	6.78	5	5		
	18-Mar-99	250	65000	6	2	10		
	12-May-99	*1000*	52000	7.83	5	5	14	30
	6-Jul-99	250	8200	5.2	5	5	8	20
	1-Sep-99	2100	16000	7.3	10	10		
	23-Nov-99	*160*	26000	5.6	2	5		
Gold Bar *WWTP*	20-Apr-98	1700	37000	6.08	110	80	6	46
	5-Oct-98	880	8100	2.3	20	1		
	5-Nov-98	3800	56000	6.98	40	27		
	9-Feb-99	8900	48000	6.27	10	5		
	19-Mar-99	*1800*	55000	7.08	36	36		
	13-May-99	*1600*	47000	5.3	100	100	14	
	15-Jul-99	1800	9500	2.92	10	10	8	20
	7-Sep-99	*250*	11000	2.1	100	60		
	23-Nov-99	*650*	32000	2.48	20	9		

Data from April 7 1998 to November 25, 1999

Italicized numbers are values below detection limit for Cryptosporidium spp. *and Giardia* spp. *and are reported as the full detection limit (21.8% (17/78) of samples were below detection limit)*

Numbers highlighted are below detection limit for Fecal coliform and *Escherichia coli* are reported as 1/2 detection limit (26.9% (21/78) of samples were below detection limit)

Table G.2 North Saskatchewan River Basin Sewage Lagoon Effluent Data 1998-1999

SITE	Date	Flow (L)	*Cryptosporidium* spp. # cysts/100L*	*Giardia* spp. # cysts/ 100L	Turbidity (NTU)	Fecal coliform (cfu/100ML)	*Escherichia coli* (cfu/100mL)	TSS (mg/L)	Colour (TCU)
Alderflats	21-Oct-99	1.50E+07	*3200*	3200	39.2	5	5		
Breton	21 Oct-99	5.23E+07	*83*	*83*	0.96	5	5		
Calmar	10-Aug-99	1.83E+08	*250*	*250*	1.44	20	10	13	15
Rocky Rapids	4-May-99	4.86E+07	1300	1300	15.14	10	10	35	80
Sunnybrook	22-Oct-98		2250	*850*	16.3	1100	480		
Thorsby	7-Oct-99	1.09E+08	1000	500	2.6	5	5		
Tomahawk (main)	7-Apr-98		1000	98000	198	63000	63000	33	94
	25-Nov-98		1000	5000	32	62000	21000		
	7-Apr-99	4.48E+06	3700	200000	227	50000	40000		
	1-Nov-99	6.58E+06	*880*	48000	22	11000	7900		
Tomahawk (school)	25-Nov-98		1800	7000	49.5	1600	700		
	1-Nov-99	1.70E+06	830	2500	30.2	170	170		
Violet Grove	8-Apr-99	2.25E+07	1900	310	75.2	5600	4500	16	100
Warburg	6-Apr-98		230000	750	19.6	6500	5500	25	61
	22-Apr-99	9.50E+07	82000	14000	23.1	32000	27000	20	70
Winfield	21 Oct-99	1.20E+07	*1500*	6000	16.3	40000	40000		

Data from April 6 1998 to November 1, 1999

Italicized numbers are values below detection limit for Cryptosporidium spp. *and Giardia* spp. *and are reported as full detection limit (25% (8/32) samples were below detection limit)*

Highlighted numbers are values below detection limit for Fecal coliform and *Escherichia coli* are reported as 1/2 detection limit (18.8% (6/32) samples were below detection limit)

Table G.3 North Saskatchewan River Basin Sewage Lagoon Discharge History 1995 - 1999

Lagoon	1999	1998	1997	1996	1995
Alderflats	Oct 18-21 V=15000 m^3, L=48 hrs	yes v=15000	yes	yes	yes
Birchwood Village	no	No	no	no	no
Breton	Oct 15-29 V=5.23E+04 m^3, L=359.1 hrs	Yes (1x during August)	yes (1x)	yes (1x)	yes (1x)
Buck Creek	June 15-June 30 v=12 100 m^3, L=230 hrs	No	no	yes	no
Calmar	Aug 3-16 V=182 500 m^3, L=312 hrs	Oct 19-31 v=182500 m^3, L=288 hrs	yes	yes	yes
Rocky Rapids	May 3-May 7 v=45 000 m^3, L=95.5 hrs	No	yes	no	yes
Sunnybrook	October 18-22 V=6 000 m^3, L=48 hrs	Oct 19-23 V=6 000 m^3, L=48 hrs	yes	yes	yes
Thorsby	Oct 12-19 v=109 200 m^3, L=168 hrs	Oct 1-10 v=109 200 m^3, L= 216 hrs	yes	yes	yes
Tomahawk (main)	April 7-8 v=4 484 m^3, L= 49.25 hrs Nov. 1-4 V=6 583 m3, L= 72 hrs	April 6-8 v=4 484 m^3, L=49 hrs Nov 25-27 v=8 322 m^3, L=48 hrs	yes (2x)	yes (2x)	yes (2x)
Tomahawk (school)	Nov 1-Nov 2 v=1 701m^3, L=25.25 hrs	Nov 25-Nov 26 v=1 560m3, L=24 hrs	yes	yes	yes
Violet Grove	April 8-April 12 v=22 500 m^3, L=118 hrs	No	yes	no	yes
Warburg	April 13- May 4 V=95000 m^3 L=504 hrs	April 6-17 v=106747m^3 * L=264 hrs			
Winfield	Oct 18-21 v=12 000 m^3, L=72 hrs	Yes (date unknown)	yes	yes	yes

*=Volume of discharge = 0.9Xcapacity

Appendix H North Saskatchewan River Basin Total Monthly Effluent Flows for Wastewater Treatment Plants Upstream of and including the City of Edmonton for 1998 and 1999

H.1 Rocky Mountain House WWTP Total Monthly Effluent Flows

H.2 Drayton Valley WWTP Total Monthly Effluent Flows

H.3 Devon WWTP Total Monthly Effluent Flows

Table H.1 Rocky Mountain House WWTP Total Monthly Effluent Flows

Month	Total Monthly Flow (m^3)		Average Monthly Flow (m^3)	Average Daily Flow (m^3)
	1998	1999		
January	56690	71908	64299	2074.2
February	49324	63331	56327.5	2011.7
March	85213	68322	76767.5	2476.4
April	85821	83826	84823.5	2827.5
May	82616	82616*	82616	2665.0
June	84466	84466*	84466	2815.5
July	106249	106249*	106249	3427.4
August	80647	80647*	80647	2601.5
September	55847	66870	61358.5	2045.3
October	70084	54096**	70084	2260.8
November	72339	49268	72339	2411.3
December	68049	43509	68049	2195.1

* flow meter malfunctioned and no reading was observed, therefore 1998 data was used as 1999 flows

** flow meter stopped working on day 18 of month, therefore to estimate a monthly total flow, the total to day 17 was added to the resultant of [0.45(% of days left in month with no flow data) x flow data for the first portion of the month]

Table H.2 Drayton Valley WWTP Total Monthly Effluent Flows

Month	Total Monthly Flow (m^3)		Average Monthly Flow (m^3)	Average Daily Flow (m^3)
	1998	1999		
January	133176	137609	135392.5	4367.5
February	121080	113088	117084	4181.6
March	127409	146570	136989.5	4419.0
April	139981	191867	165924	5530.8
May	162163	184546	173354.5	5592.1
June	197844	158018	177931	5931.0
July	224892	177697	201294.5	6493.4
August	208430	155788	182109	5874.5
September	169441	139001	154221	5140.7
October	182366	85582	182366	5882.8
November	140018	48691	140018	4667.3
December	134795	108819	134795	4348.2

Table H.3 Devon WWTP Total Monthly Effluent Flows

Month	Total Monthly Flow (m^3)		Average Monthly Flow (m^3)	Average Daily Flow (m^3)
	1998	1999		
January	52901	54524	53712.5	1732.7
February	48118	49958	49038	1751.4
March	55198	58607	56902.5	1835.6
April	53816	60533	57174.5	1905.8
May	60622	72000	66311	2139.1
June	61257	67731	64494	2149.8
July	69725	77915	73820	2381.3
August	62752	66148	64450	2079.0
September	57449	58995	58671.5	1955.7
October	57712	58400	57712	1861.7
November	54962	56955	54962	1832.1
December	54755	57880	54755	1766.3

Table H.4 Gold Bar WWTP Total Monthly Effluent Flows

Month	Total Monthly Flow (m^3)		Average Monthly Flow (m^3)	Average Daily Flow (m^3)
	1998	1999		
January	6464600	6699490	6582045	212324.0
February	6058400	6191860	6125130	218754.6
March	7206600	7702940	7454770	240476.5
April	7086300	7553300	7319800	243993.3
May	7974400	8720100	8347250	269266.1
June	8225540	8121070	8173305	272443.5
July	9209320	8723810	8966565	289244.0
August	9276800	8315190	8795995	283741.8
September	8053700	7730160	7891930	263064.3
October	7847400	7400990	7624195	245941.8
November	6909640	6712320	6810980	227032.7
December	6616700	6703090	6659895	214835.3

Appendix I: Comparative Watershed Study Results, Combined with Upstream/Downstream Monitoring of Three Farms

I.1 Tomahawk Creek Watershed Results 1999

I.2 Weed Creek Watershed Results 1999

I.3 Mishow Creek Watershed Results 1999

I.4 Strawberry Creek Watershed Results 1999

I.5 Nordegg River Watershed Results 1999

I.6 Baptiste River Watershed Results 1999

Table I.1: Tomahawk Creek Watershed Results, 1999

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
Near Mouth	2-Apr-99	0.251	*120*	250	16.2	20	9
	8-Apr-99	1.43	56	170	28.7	560	560
	12-Apr-99	6.75	4900	3700	168	150	150
	15-Apr-99	9.59	*4100*	*4100*	240	54	54
	18-Apr-99	6.36	*4000*	*4000*	270	60	60
	21-Apr-99	2.57	*480*	*480*	79	20	10
	23-Apr-99	2.12	*150*	150	40	20	10
	28-Apr-99	2.25	460	*460*	69	100	100
	5-May-99	3.1	*500*	500	110	180	180
	12-May-99	0.763	67	67	18	120	120
	23-Jun-99	0.075	*172*	170	26.6	280	280
	8-Jul-99	3.59	2000	2000	135	4200	2200
	9-Jul-99	1.7	*700*	700	91.7		
	10-Jul-99	1.11	1800	3200	53.6	660	400
	13-Jul-99	0.368	270	1090	15.7	330	190
	30-Sep-99		100	1000			
Downstream	12-Apr-99	0.286	4100	*520*	4.2	120	120
	15-Apr-99	0.752	7500	*140*	2.7	90	90
	18-Apr-99	0.509	2300	200	1.7	10	10
	20-Apr-99	0.483	1200	10	1.7	50	50
	23-Apr-99		410	*8*	0.59	30	5
	28-Apr-99	0.216	70	5	0.88	230	230
	5-May-99	0.312	72	5	1.8	30	10
	12-May-99	0.129	180	83	1.6	10	5
	8-Jul-99	0.263	7400	150	15.3	7700	5900
	9-Jul-99	0.231	410	30	3.3	800	300

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
	10-Jul-99	0.264	480	50	2	630	630
	13-Jul-99	0.111	60	20	5.27	100	100
Upstream	12-Apr-99	0.286	4200	320	10.2	20	20
	15-Apr-99	0.752	25000	*210*	3.62	170	70
	18-Apr-99	0.509	2600	50	2.7	30	30
	21-Apr-99	0.483	550	*25*	1.4	80	70
	23-Apr-99		100	6.3	1.4	30	30
	28-Apr-99	0.216	140	8	2.6	10	10
	5-May-99	0.312	208	10	1.1	10	10
	12-May-99	0.129	200	36	1.1	20	20
	8-Jul-99	0.263	7700	83	2.33	460	460
	9-Jul-99	0.231	550	100	2	400	100
	10-Jul-99	0.264	700	60	4.8	110	82
	13-Jul-99	0.111	10	5	0.82	60	30

cfu = coliform forming unit, NTU = nephalometric turbidity unit

Table I.2: Weed Creek Watershed Study Results, 1999

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
Near Mouth	3-Apr-99	1.59	450	1400	20.4		
	8-Apr-99	17.4	7900	20000	480	140	90
	11-Apr-99	13.1	6200	*1600*	460	140	140
	14-Apr-99	3.1	7600	1900	133	30	10
	20-Apr-99	0.745	400	200	15	70	20
	27-Apr-99	0.615	140	490	14	80	40
	4-May-99	0.5	420	1300	96	240	150
	11-May-99	0.386	*12*	25	5.6	10	5

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
	24-Jun-99	0.034	*50*	150	5.58	650	650
	8-Jul-99	0.211	*100*	200	12.9	550	550
	9-Jul-99	3.92	*3200*	*3200*	257	2100	1700
	10-Jul-99	1.42	1500	1200	48.4	790	790
	13-Jul-99	0.17	*25*	50	12.8	170	170
	28-Sep-99		75	300			
Downstream	3-Apr-99	1.02	4300	2000	5.8		
	8-Apr-99	3.37	1200	3800	114	550	550
	11-Apr-99	0.198	1000	1000	27.2	130	130
	14-Apr-99	0.806				20	20
	20-Apr-99	0.29	12	360	4	510	510
	27-Apr-99	0.133	50	180	3.7	30	30
	4-May-99	0.741	33	370	6.1	270	220
	11-May-99	0.057	*12*	25	2.4	20	5
	8-Jul-99	0.061	800	450	36	3400	2800
	9-Jul-99	0.801	500	250	30.3	5700	5700
	10-Jul-99	0.378	*25*	75	9.4	590	540
	13-Jul-99	0.024	*25*	*25*	3.92	280	190
Upstream at Twp Rd	3-Apr-99	0.554	3000	380	2.74		
	8-Apr-99	1.52	*750*	*750*	44.8	200	100
	11-Apr-99	1.05	200	*200*	9.9	360	270
	14-Apr-99	0.423	*100*	300	8.64	250	250
	20-Apr-99	0.168	*33*	1500	2.5	760	760
	27-Apr-99	0.074	20	480	2.9	900	600
	4-May-99	0.5	50	150	6.2	790	760
	11-May-99	0.024	*12*	87	3.6	1000	2100
	8-Jul-99	1.04	270	270	12.2	1000	1000

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
	9-Jul-99	0.608	120	25	11.3	5600	3700
	10-Jul-99	0.123	60	*10*	14.6	1800	1800
	13-Jul-99	0.003	*120*	*120*	10.8	20	20
	28-Sep-99		*75*	*75*			
Upstream at Hwy 778	3-Apr-99	0.189	1200	190	3.46		
	8-Apr-99	0.972	750	750	16	64	55
	11-Apr-99	1	1600	260	7	20	20
	14-Apr-99	0.435	75	200	3.92	10	10
	20-Apr-99	0.144	58	99	2.9	5	5
	27-Apr-99	0.05	*8*	75	3.9	10	10
	4-May-99	0.242	51	180	2.2	100	100
	11-May-99	0.018	12	*12*	1.6	20	20
	8-Jul-99	0.014	3100	170	17.9	230	80
	9-Jul-99	0.003	320	25	7.3	70	70
	10-Jul-99	0.121	*50*	150	8.6	2000	1900
	13-Jul-99	0.361	*50*	*50*	4.32	5	5

cfu = coliform forming unit
NTU = nephalometric turbidity unit

Table I.3: Mishow Creek Watershed Study Results, 1999

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
Near Mouth	7-Apr-99	0.727	350	2800	34.1	5	5
	10-Apr-99	4.98	3500	1800	84.7	100	45
	13-Apr-99	15.4	8700	4400	368	100	100
	16-Apr-99	6.7	6000	*6000*	710	100	100
	19-Apr-99	3.21	2700	*1300*	280	20	20

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
	22-Apr-99	1.26	*870*	870	88	60	20
	26-Apr-99	0.545	*460*	910	66	160	160
	3-May-99	6.04	2800	2800	2.4	480	370
	10-May-99	0.373	330	170	39	30	30
	22-Jun-99	0.014	*48*	1200	14.4	100	100
	8-Jul-99	1.09	*1200*	12000	124	1800	1800
	9-Jul-99	0.448	*300*	*300*	85	2200	2200
	30-Sep-99		25	33			
Downstream	7-Apr-99	0.261	820	1100	14.1	70	70
	10-Apr-99	1.96	*500*	500	20.8	36	10
	13-Apr-99	3.19	720	*720*	51.6	160	160
	16-Apr-99	3.08	3200	2400	49	100	40
	19-Apr-99	0.882	1200	*250*	49	30	30
	22-Apr-99	0.351	*62*	190	18	30	30
	26-Apr-99	0.145	120	750	26	130	130
	3-May-99		*1800*	5500	100	330	330
	10-May-99	0.073	*330*	*330*	28	150	100
	8-Jul-99	0.614	900	9900	48	3800	3400
	9-Jul-99	0.144	620	500	34.8	2100	1600
Upstream	7-Apr-99	0.261	45	90	23.8	130	130
	10-Apr-99	1.96	3400	1600	14.9	82	82
	13-Apr-99	3.19	2400	400	42.3	20	20
	16-Apr-99	3.08	980	980	41	40	40
	19-Apr-99	0.882	890	74	36	10	10
	22-Apr-99	0.351	*75*	75	18	10	5
	26-Apr-99	0.145	*99*	890	24	20	20
	3-May-99		910	910	110	210	210

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Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
	10-May-99	0.073	250	250	19	20	20
	8-Jul-99	0.614	*530*	1100	32.7	3100	2200
	9-Jul-99	0.144	380	880	31.1	600	600

cfu = coliform forming unit
NTU = nephalometric turbidity unit

Table I.4: Strawberry Creek Watershed Study Results, 1999

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
Mouth	9-Apr-99	37.7	2800	42000	710	350	350
	13-Apr-99	39.2	18000	18000	>2000	200	110
	16-Apr-99	9.6	*1700*	1700	270	30	30
	20-Apr-99	4.1	810	810	120	20	5
	23-Apr-99	2.55	*510*	2600	72	40	20
	28-Apr-99	1.56	*270*	820	82	70	70
	6-May-99	2.37	292	1500	54	40	40
	13-May-99	0.5	*62*	120	12	5	5
	23-Jun-99	0.404	*83*	670	18	170	170
	8-Jul-99	2.94	*840*	840	95	350	350
	9-Jul-99	12.9	*5700*	5700	870	4000	4000
	10-Jul-99	6.35	*2400*	4800	312	1600	1000
	13-Jul-99	0.902	400	800	45.5	190	140
	15-Jul-99	0.948	400	790	203	530	530
	28-Sep-99		*300*	7800			

cfu = coliform forming unit, NTU = nephalometric turbidity unit

Table I.5: Nordegg River Watershed Study Results, 1999

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
Sunchild Road	16-Apr-99	3.82	170	50	1.99	5	5
	22-Apr-99	11.7	*350*	350	35	10	5
	27-Apr-99	11.2	300	100	15	5	5
	30-Apr-99	8.7	*25*	25	7.4	5	5
	3-May-99	9.51	20	60	9	5	5
	10-May-99	5.26	*50*	*50*	3.8	5	5
	29-Jun-99	3.84	*300*	300	10.6	40	40
	9-Jul-99	44.814	*400*	*400*	76.4	10	10
	12-Jul-99	15.666	250	*250*	22	5	5
	15-Jul-99	138.296	7900	*7900*	968	580	360

cfu = coliform forming unit
NTU = nephalometric turbidity unit

Tablel.6 : Baptiste River Watershed Study Results, 1999

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform Cfu/100mL	*Escherichia coli* Cfu/100 mL
Mouth	16-Apr-99	8.4	550	300	14	5	5
	22-Apr-99	15.7	*460*	1400	52		
	27-Apr-99	17.1	180	180	22	10	5
	30-Apr-99	17.7	*50*	250	15	5	5
	3-May-99	15.6	*38*	38	7.6	10	10
	10-May-99	8.98	*10*	30	3.4	5	5
	29-Jun-99	12.453	100	300	6.1	30	10
	9-Jul-99	97.536	6200	*1500*	154	60	50
	12-Jul-99	37.442	500	1500	24	30	30
	15-Jul-99	124.422	13000	*4400*	97.2	280	280

Site	Date	Flow m^3/s	*Cryptosporidium* spp. Oocysts/100L	*Giardia* spp. Cysts/100L	Turbidity NTU	Fecal Coliform cfu/100mL	*Escherichia coli* cfu/100 mL
	29-Sep-99		*10*	200			
Sunchild	16-Apr-99		220	430	1.43	10	10
Road	22-Apr-99		390	540	5.1	5	5
	27-Apr-99	7.39	260	190	3.8	30	30
	30-Apr-99	6.35	*15*	200	3.2	10	10
	3-May-99	5.62	*12*	50	1.8	5	5
	10-May-99	2.7	5	85	1.2	5	5
	29-Jun-99	7.53	25	480	2.64	40	40
	9-Jul-99	44.9	800	1200	45.4	90	50
	15-Jul-99		2700	*2700*	350	260	260

cfu = coliform forming unit

NTU = nephalometric turbidity unit

Italicized numbers are values that were below detection limit for Cryptosporidium spp. *and Giardia* spp. *and are reported as full detection limit values (26.8% (91/340) samples were below the detection limit for all Comparative Watershed results)*

Highlighted numbers are values that were below detection limit for Fecal Coliform and *Escherichia coli* and are reported as ½ the detection limit. (12.5% (40/320) of samples were below detection limit for all Comparative Watershed results)

Appendix J: Raw Water *Cryptosporidium* spp. and *Giardia* spp. Concentrations at the E.L. Smith and Rossdale WTP 1992-1999

J.1: Concentrations at the EL Smith WTP 1992-1999

J.2 Concentrations at the Rossdale WTP 1992-1999

Table J.1 Concentrations at the EL Smith WTP

Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
14-Dec-92	*2*	*2*	8.08E+09	1.62E+08	1.62E+08
26-Jan-93	*2*	*2*	1.03E+10	2.06E+08	2.06E+08
22-Feb-93	*4*	*4*	1.17E+10	4.67E+08	4.67E+08
22-Mar-93	4	*4*	9.33E+09	3.73E+08	3.73E+08
27-Apr-93	*100*	*100*	1.70E+10	1.70E+10	1.70E+10
25-May-93	*14*	*14*	1.81E+10	2.54E+09	2.54E+09
28-Jun-93	*21*	*21*	2.00E+10	4.19E+09	4.19E+09
19-Jul-93	82	*41*	2.06E+10	1.69E+10	8.47E+09
23-Aug-93	11	*5*	5.11E+10	5.62E+09	2.55E+09
20-Sep-93	21	*4*	1.51E+10	3.18E+09	6.05E+08
25-Oct-93	3.4	*3*	1.24E+10	4.23E+08	3.73E+08
25-Nov-93	19	*6*	3.33E+09	6.32E+08	2.00E+08
6-Dec-93	6.8	*1*	1.26E+10	8.58E+08	1.26E+08
24-Jan-94	32	*16*	1.14E+10	3.65E+09	1.82E+09
14-Feb-94	3	*3*	8.81E+09	2.64E+08	2.64E+08
14-Mar-94	42	*3*	8.53E+09	3.58E+09	2.56E+08
18-Apr-94	800	620	2.27E+10	1.82E+11	1.41E+11
17-May-94	62	44	1.25E+10	7.77E+09	5.51E+09
14-Jun-94	88	88	3.32E+10	2.92E+10	2.92E+10
25-Jul-94	48	12	1.53E+10	7.34E+09	1.84E+09
22-Aug-94	67	45	1.64E+10	1.10E+10	7.39E+09
26-Sep-94	35	9	1.09E+10	3.81E+09	9.80E+08
17-Oct-94	126	5	9.76E+09	1.23E+10	4.88E+08
21-Nov-94	30	15	8.81E+09	2.64E+09	1.32E+09
5-Dec-94	45	*3*	8.01E+09	3.60E+09	2.40E+08

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Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
23-Jan-95	6	*3*	9.42E+09	5.65E+08	2.83E+08
13-Feb-95	10	*5*	7.93E+09	7.93E+08	3.97E+08
20-Mar-95	93	13	1.46E+10	1.36E+10	1.90E+09
24-Apr-95	408	136	1.70E+10	6.94E+10	2.31E+10
15-May-95	521	391	2.23E+10	1.16E+11	8.72E+10
12-Jun-95	105	*105*	3.66E+10	3.85E+10	3.85E+10
24-Jul-95	79	23	2.32E+10	1.84E+10	5.35E+09
21-Aug-95	21	*21*	2.96E+10	6.22E+09	6.22E+09
18-Sep-95	63	12	1.15E+10	7.24E+09	1.38E+09
16-Oct-95	68	*23*	1.31E+10	8.93E+09	3.02E+09
20-Nov-95	52	*10*	1.46E+10	7.59E+09	1.46E+09
11-Dec-95	16	*7*	1.04E+10	1.66E+09	7.26E+08
15-Jan-96	31	6	8.99E+09	2.79E+09	5.39E+08
12-Feb-96	56	46	1.14E+10	6.39E+09	5.25E+09
11-Mar-96	38	138	1.07E+10	4.07E+09	1.48E+10
22-Apr-96	480	2400	2.51E+10	1.21E+11	6.03E+11
13-May-96	10	10	1.44E+10	1.44E+09	1.44E+09
10-Jun-96	60	*30*	3.49E+10	2.09E+10	1.05E+10
15-Jul-96	38	*48*	1.73E+10	6.57E+09	8.29E+09
26-Aug-96	75	12	1.39E+10	1.04E+10	1.67E+09
16-Sep-96	10	*3*	8.64E+09	8.64E+08	2.59E+08
7-Oct-96	39	5	8.64E+09	3.37E+09	4.32E+08
18-Nov-96	57	*19*	4.40E+09	2.51E+09	8.36E+08
9-Dec-96	80	*7*	7.97E+09	6.37E+09	5.58E+08
13-Jan-97	42	42	9.42E+09	3.96E+09	3.96E+09
10-Feb-97	53	53	9.42E+09	4.99E+09	4.99E+09

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Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
17-Mar-97	42	28	8.21E+09	3.45E+09	2.30E+09
1-Apr-97	2500	9000	1.99E+10	4.97E+11	1.79E+12
21-Apr-97	1800	9000	2.93E+10	5.27E+11	2.64E+12
12-May-97	270	55	1.43E+10	3.87E+10	7.89E+09
9-Jun-97	250	*50*	1.92E+10	4.80E+10	9.59E+09
14-Jul-97	120	*120*	2.63E+10	3.15E+10	3.15E+10
18-Aug-97	580	150	2.98E+10	1.73E+11	4.47E+10
25-Aug-97	65	*16*	1.72E+10	1.12E+10	2.75E+09
15-Sep-97	170	20	1.51E+10	2.57E+10	3.02E+09
14-Oct-97	440	55	1.46E+10	6.42E+10	8.03E+09
17-Nov-97	220	31	1.12E+10	2.47E+10	3.48E+09
8-Dec-97	150	150	1.22E+10	1.83E+10	1.83E+10
19-Jan-98	29	*5.7*	8.48E+09	2.46E+09	4.83E+08
2-Feb-98	11	*11*	8.81E+09	9.69E+08	9.69E+08
9-Mar-98	29	10	1.21E+10	3.51E+09	1.21E+09
7-Apr-98	*28*	*28*	1.61E+10	4.50E+09	4.50E+09
27-Apr-98	60	300	1.30E+10	7.83E+09	3.91E+10
11-May-98	130	*21*	9.50E+09	1.24E+10	2.00E+09
15-Jun-98	*56*	*56*	2.17E+10	1.21E+10	1.21E+10
13-Jul-98	340	230	6.07E+10	2.06E+11	1.40E+11
10-Aug-98	108	*27*	1.99E+10	2.15E+10	5.37E+09
21-Sep-98	110	22	1.43E+10	1.57E+10	3.14E+09
26-Oct-98	440	*20*	1.43E+10	6.27E+10	2.85E+09
16-Nov-98	110	*23*	7.78E+09	8.55E+09	1.79E+09
7-Dec-98	19	*6.3*	1.18E+10	2.23E+09	7.40E+08
25-Jan-99	*28*	*28*	1.39E+10	3.89E+09	3.89E+09

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Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
8-Feb-99	21	*21*	1.38E+10	2.90E+09	2.90E+09
1-Mar-99	100	20	1.11E+10	1.11E+10	2.23E+09
15-Mar-99	6	6	1.30E+10	7.78E+08	7.78E+08
29-Mar-99	110	73	1.83E+10	2.01E+10	1.34E+10
7-Apr-99	50	50	1.66E+10	8.29E+09	8.29E+09
10-Apr-99	4600	4600	3.58E+10	1.65E+12	1.65E+12
15-Apr-99	3100	1000	3.14E+10	9.75E+11	3.14E+11
28-Apr-99	270	140	2.96E+10	8.00E+10	4.15E+10
10-May-99	280	280	1.90E+10	5.32E+10	5.32E+10
14-Jun-99	43	*43*	1.23E+10	5.28E+09	5.28E+09
12-Jul-99	910	*910*	6.58E+10	5.99E+11	5.99E+11
16-Aug-99	*95*	190	2.36E+10	2.24E+10	4.48E+10
20-Sep-99	220	75	1.86E+10	4.09E+10	1.39E+10
18-Oct-99	280	140	1.13E+10	3.17E+10	1.58E+10
18-Nov-99	540	19	9.50E+09	5.13E+10	1.81E+09
20-Dec-99	130	13	8.21E+09	1.07E+10	1.07E+09

Italicized numbers are values that are below detection limit and are reported as full detection limit (29.8% (53/178) samples were below detection limit for EL Smith WTP raw water samples, December 14, 1992 to December 20, 1999).

Table J.2 Concentrations at the Rossdale WTP 1992-1999

Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
14-Dec-92	*5*	*5*	8.08E+09	4.04E+08	4.04E+08
26-Jan-93	*6*	*6*	1.03E+10	6.17E+08	6.17E+08
22-Feb-93	10	*4*	1.17E+10	1.17E+09	4.67E+08
22-Mar-93	*6*	*6*	9.33E+09	5.60E+08	5.60E+08
27-Apr-93	*60*	*60*	1.70E+10	1.02E+10	1.02E+10
25-May-93	*17*	*17*	1.81E+10	3.08E+09	3.08E+09
28-Jun-93	*42*	83	2.00E+10	8.38E+09	1.66E+10
19-Jul-93	*46*	*46*	2.06E+10	9.50E+09	9.50E+09
23-Aug-93	188	*38*	5.11E+10	9.60E+10	1.94E+10
20-Sep-93	16	*5*	1.51E+10	2.42E+09	7.56E+08
25-Oct-93	3.7	*4*	1.24E+10	4.60E+08	4.98E+08
25-Nov-93	22	*6*	3.33E+09	7.32E+08	2.00E+08
06-Dec-93	15.1	*89*	1.26E+10	1.90E+09	1.12E+10
24-Jan-94	206	*16*	1.14E+10	2.35E+10	1.82E+09
14-Feb-94	107	*3*	8.81E+09	9.43E+09	2.64E+08
14-Mar-94	259	18	8.53E+09	2.21E+10	1.53E+09
18-Apr-94	600	*150*	2.27E+10	1.36E+11	3.41E+10
17-May-94	163	*18*	1.25E+10	2.04E+10	2.26E+09
14-Jun-94	105	*105*	3.32E+10	3.48E+10	3.48E+10
25-Jul-94	142	19	1.53E+10	2.17E+10	2.91E+09
22-Aug-94	446	67	1.64E+10	7.32E+10	1.10E+10
26-Sep-94	400	27	1.09E+10	4.35E+10	2.94E+09
17-Oct-94	780	36	9.76E+09	7.62E+10	3.51E+09
21-Nov-94	232	5	8.81E+09	2.04E+10	4.41E+08
05-Dec-94	10	2.5	8.01E+09	8.01E+08	2.00E+08
23-Jan-95	51	5	9.42E+09	4.80E+09	4.71E+08

Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
13-Feb-95	108	*5*	7.93E+09	8.57E+09	3.97E+08
20-Mar-95	200	33	1.46E+10	2.92E+10	4.82E+09
24-Apr-95	640	40	1.70E+10	1.09E+11	6.81E+09
15-May-95	268	357	2.23E+10	5.97E+10	7.96E+10
12-Jun-95	156	104	3.66E+10	5.71E+10	3.81E+10
24-Jul-95	129	*10*	2.32E+10	3.00E+10	2.32E+09
21-Aug-95	60	*60*	2.96E+10	1.78E+10	1.78E+10
18-Sep-95	335	28	1.15E+10	3.85E+10	3.22E+09
16-Oct-95	150	*17*	1.31E+10	1.97E+10	2.23E+09
20-Nov-95	22	17	1.46E+10	3.21E+09	2.48E+09
11-Dec-95	22	56	1.04E+10	2.28E+09	5.81E+09
15-Jan-96	124	120	8.99E+09	1.11E+10	1.08E+10
12-Feb-96	108	29	1.14E+10	1.23E+10	3.31E+09
11-Mar-96	525	75	1.07E+10	5.62E+10	8.04E+09
13-Mar-96	126	661	1.03E+10	1.30E+10	6.80E+10
22-Apr-96	140	570	2.51E+10	3.52E+10	1.43E+11
13-May-96	75	75	1.44E+10	1.08E+10	1.08E+10
10-Jun-96	145	*73*	3.49E+10	5.06E+10	2.55E+10
15-Jul-96	20	9	1.73E+10	3.46E+09	1.56E+09
26-Aug-96	74	25	1.39E+10	1.03E+10	3.48E+09
16-Sep-96	77	13	8.64E+09	6.65E+09	1.12E+09
07-Oct-96	165	18	8.64E+09	1.43E+10	1.56E+09
18-Nov-96	127	*7*	4.40E+09	5.59E+09	3.08E+08
09-Dec-96	122	15	7.97E+09	9.72E+09	1.19E+09
13-Jan-97	71	28	9.42E+09	6.69E+09	2.64E+09
10-Feb-97	138	50	9.42E+09	1.30E+10	4.71E+09
17-Mar-97	250	*28*	8.21E+09	2.05E+10	2.30E+09

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Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
20-Mar-97	1200	1200	1.00E+10	1.20E+11	1.20E+11
21-Mar-97	940	470	9.94E+09	9.34E+10	4.67E+10
27-Mar-97	585	65	9.68E+09	5.66E+10	6.29E+09
01-Apr-97	2300	10000	1.99E+10	4.57E+11	1.99E+12
04-Apr-97	340	2200	1.62E+10	5.52E+10	3.57E+11
09-Apr-97	710	1000	8.90E+09	6.32E+10	8.90E+10
14-Apr-97	1700	3300	2.07E+10	3.53E+11	6.84E+11
21-Apr-97	1100	8900	2.93E+10	3.22E+11	2.61E+12
24-Apr-97	890	4400	2.70E+10	2.41E+11	1.19E+12
30-Apr-97	490	1500	2.33E+10	1.14E+11	3.50E+11
05-May-97	660	990	2.13E+10	1.41E+11	2.11E+11
12-May-97	340	140	1.43E+10	4.88E+10	2.01E+10
20-May-97	120	200	1.11E+10	1.34E+10	2.23E+10
26-May-97	370	1100	2.25E+10	8.31E+10	2.47E+11
09-Jun-97	220	170	1.92E+10	4.22E+10	3.26E+10
14-Jul-97	337	48	2.63E+10	8.85E+10	1.26E+10
18-Aug-97	1100	*100*	2.98E+10	3.28E+11	2.98E+10
25-Aug-97	760	43	1.72E+10	1.31E+11	7.39E+09
15-Sep-97	910	31	1.51E+10	1.38E+11	4.69E+09
14-Oct-97	440	68	1.46E+10	6.42E+10	9.93E+09
10-Nov-97	270	15	1.25E+10	3.38E+10	1.88E+09
17-Nov-97	110	27	1.12E+10	1.24E+10	3.03E+09
01-Dec-97	177	9	1.22E+10	2.16E+10	1.10E+09
08-Dec-97	190	42	1.22E+10	2.31E+10	5.12E+09
05-Jan-98	28	*9.2*	7.34E+09	2.06E+09	6.76E+08
19-Jan-98	7.6	*7.6*	8.48E+09	6.44E+08	6.44E+08
02-Feb-98	*12*	*12*	8.81E+09	1.06E+09	1.06E+09

Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
17-Feb-98	23	15	9.59E+09	2.21E+09	1.44E+09
09-Mar-98	30	10	1.21E+10	3.63E+09	1.21E+09
16-Mar-98	81	18	1.04E+10	8.40E+09	1.87E+09
26-Mar-98	36	84	1.06E+10	3.83E+09	8.93E+09
06-Apr-98	66	110	1.57E+10	1.04E+10	1.73E+10
27-Apr-98	*120*	720	1.30E+10	1.57E+10	9.39E+10
04-May-98	*130*	1100	1.39E+10	1.81E+10	1.53E+11
11-May-98	20	*10*	9.50E+09	1.90E+09	9.50E+08
01-Jun-98	*85*	*85*	2.38E+10	2.02E+10	2.02E+10
15-Jun-98	*72*	72	2.17E+10	1.56E+10	1.56E+10
24-Jun-98	900	22000	3.66E+10	3.30E+11	8.06E+12
03-Jul-98	*740*	4500	1.00E+11	7.42E+11	4.51E+12
13-Jul-98	*84*	84	6.07E+10	5.09E+10	5.09E+10
10-Aug-98	88	29	1.99E+10	1.75E+10	5.76E+09
21-Sep-98	110	32	1.43E+10	1.57E+10	4.56E+09
26-Oct-98	290	38	1.43E+10	4.13E+10	5.42E+09
16-Nov-98	90	45	7.78E+09	7.00E+09	3.50E+09
07-Dec-98	37	390	1.18E+10	4.35E+09	4.58E+10
25-Jan-99	*61*	*61*	1.39E+10	8.49E+09	8.49E+09
08-Feb-99	30	30	1.38E+10	4.15E+09	4.15E+09
01-Mar-99	85	28	1.11E+10	9.47E+09	3.12E+09
15-Mar-99	120	50	1.30E+10	1.56E+10	6.48E+09
29-Mar-99	360	36	1.83E+10	6.59E+10	6.59E+09
07-Apr-99	530	530	1.66E+10	8.79E+10	8.79E+10
10-Apr-99	870	1700	3.58E+10	3.11E+11	6.08E+11
15-Apr-99	1500	1500	3.14E+10	4.72E+11	4.72E+11
28-Apr-99	*110*	110	2.96E+10	3.26E+10	3.26E+10

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Date Sampled	*Giardia* spp. Cysts/100L	*Cryptosporidium* spp. Oocysts/100L	Flow at Edmonton L/d	*Giardia* spp. Load # cysts/d	*Cryptosporidium* spp. Load # oocysts/d
10-May-99	160	*160*	1.90E+10	3.04E+10	3.04E+10
14-Jun-99	67	*22*	1.23E+10	8.22E+09	2.70E+09
12-Jul-99	*580*	*580*	6.58E+10	3.82E+11	3.82E+11
16-Aug-99	*110*	*110*	2.36E+10	2.59E+10	2.59E+10
20-Sep-99	510	*100*	1.86E+10	9.47E+10	1.86E+10
18-Oct-99	500	20	1.13E+10	5.66E+10	2.26E+09
15-Nov-99	510	12	9.50E+09	4.85E+10	1.14E+09
20-Dec-99	40	5	8.21E+09	3.28E+09	4.10E+08

Italicized numbers are values that are below detection limit and are reported as full detection limit. (24.1% (54/224) samples were below detection limit for Rossdale WTP raw water samples Dec.14, 1992 to December 20, 1999).