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Investigating the relationship between drinking water and gastroenteritis in Edmonton: 1993-1998

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SECTION 5: DISCUSSION AND CONCLUSIONS

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[a] ENDS is a multi-disciplinary working-group with a mandate to develop, prioritize, and promote enteric disease related surveillance activities. Included on the ENDS Committee are representatives from several Provincial Ministries of Health, Health Canada, Medical Officers of Health and Public Health Inspectors, representatives from Federal and Provincial Ministries' of Agriculture and Environment, and individuals representing both the food and water industries in Canada.

Executive Summary

The risk of microbial disease associated with drinking water is presently a priority concern among North American water jurisdictions. Numerous past outbreaks, together with recent studies suggesting that drinking water may be a substantial contributor to endemic (non-outbreak related) gastroenteritis, demonstrate the vulnerability of many North American cities to waterborne diseases. These findings have fuelled ongoing debates in Canada and the United States, and highlight the need for stricter water quality guidelines, changes in watershed management policies, and the need for additional water treatment.

EPCOR Water Services Inc. supplies water to the city of Edmonton and its surrounding region through two water treatment plants. The Rossdale plant has been upgraded several times since its initial construction during the 1940's, while the E.L. Smith treatment plant was built in 1976. Both plants draw raw water from the North Saskatchewan River, and utilise clarification, softening, recarbonation, filtration, and disinfection in the water treatment process. Downstream of the E.L. Smith plant and upstream of the Rossdale plant, are 85 stormsewers that discharge into the North Saskatchewan River. Covering 28,000 square kilometres, the North Saskatchewan River watershed has many potential points of pathogen introduction: recreational sites, treated wastewater discharge from upstream communities, private septic systems, and agricultural operations. An event of particular interest in this study, was the relocation of the Rossdale raw water intake site on December 10, 1997. The site was moved towards the centre of the river in an attempt to improve raw water quality. Also concurrent with this event was the introduction of particle counters at the Rossdale plant, which allowed for the optimisation of filter performance.

The primary objective of this investigation was to determine if endemic gastroenteritis among Edmonton residents was influenced by the municipal water supply between 1993 to 1998. Several analytic techniques were used to achieve the study objectives. Multivariate logistic regression using generalised linear (GLM) and generalised additive models (GAM) was used to determine if differences in risk for endemic gastroenteritis (as assessed by hospital admissions, emergency room visits, physician visits, and long-term care visits) existed among the water service areas (Rossdale vs. E.L. Smith), both prior and subsequent to the implementation of changes at the Rossdale plant on December 10, 1997 (relocation of the intake pipe and the introduction of particle counters).

A time series approach using generalised additive models (GAM) was used to investigate and quantify the temporal association between gastrointestinal-related health outcomes on a specific day

(as assessed by hospital admissions, emergency room visits, physician visits, and long-term care visits) and environmental and water quality parameters (primarily finished water turbidity). Observed values for these parameters from 0 to 40 days prior to a health outcome event were assessed for their impact on the measured health outcomes. In addition to daily readings of finished water turbidity, the utility of particle counts data were assessed, together with raw water indicators including turbidity and coliform counts. Environmental parameters, including daily precipitation and maximum and minimum temperatures, were also investigated.

As anticipated, descriptive analyses and summary statistics of the raw water parameters indicated better quality of water entering the E.L. Smith plant in comparison to the Rossdale plant, both before and after December 10, 1997. These differences are most pronounced in daily total and faecal coliforms. Following December 10, 1997, the differences in raw water parameters between the plants are less prominent. Of primary interest for the time series analysis was the daily finished water turbidity. Prior to December 10, 1997, finished water turbidity values (mean and median) were slightly lower for the E.L. Smith plant. Following December 10, 1997, finished water turbidity values were equivalent between the two plants. Mean and median particle counts from the E.L. Smith plant were marginally lower compared to those of the Rossdale plant. However, particle count data were only available for 1998. Throughout the period of investigation (1993-1998), finished water turbidity levels for both plants were well within federal (Health Canada, 1996) and provincial (Alberta Environment Protection, 1997) drinking water turbidity guidelines.

Results of the multivariate logistic model which fit a categorical variable for water source (GLM), suggest a slight decrease in the risk of gastroenteritis among residents supplied with Rossdale water following the changes that were implemented on December 10, 1997. The interpretation of the logistic regression results should, however, be made with caution as the magnitude of the effects were relatively small (odds ratios near one). Although it is plausible that this effect was due to the improvements at the Rossdale plant, other combinations of events could have resulted in a similar relationship. An obvious spatial pattern in gastroenteritis risk with respect to water plant service area was not identified using spatial regression models (GAM). This latter observation further underlies the tenuous nature of this causal hypothesis.

Given the descriptive findings, and the results of the multivariate logistic modelling, time series analysis was restricted to households supplied by the Rossdale water treatment plant prior to December 10, 1997. It was anticipated that if a temporal relationship between daily water quality and gastroenteritis existed, it would be most likely identified in this subset. Nevertheless, no significant lags were identified between daily finished water turbidity and gastroenteritis among Rossdale serviced residents (prior to December 10, 1997) using time series analysis. Lagged water quality parameters from 0 to 40 days prior to health outcome events were assessed for statistical significance and biological relevance using a time series approach. Finished water turbidity provided the best fit to the data. None of the raw water nor environmental parameters were adequate predictors of health in the final model. Similar to the spatial analysis, seasonal and temporal effects were adjusted for use in the final model. Despite limiting the analysis to the water supply posing the greatest potential risk, the time series analysis failed to identify temporal relationships between the finished water turbidity from the Rossdale plant prior to December 10, 1997 and endemic gastroenteritis.

In comparison to the results of the Vancouver time series study[1], evidence in the present study suggests very little impact, if any, of drinking water on the level of endemic gastroenteritis among Edmonton residents. Despite markedly poorer raw water quality in Edmonton compared to Vancouver during the respective study periods, no significant temporal relationships were identified between water quality parameters and the risk of gastroenteritis. The lack of a temporal relationship supports the opinion that the high quality of Edmonton's drinking water adequately minimises the risk of waterborne endemic gastroenteritis. Furthermore, the lack of a significant relationship between raw water turbidity and faecal coliform counts and endemic gastroenteritis supports the effectiveness of the treatment processes utilised.

Under the multivariate logistic regression model, the suggestion of an overall decrease in risk of endemic gastroenteritis among Rossdale serviced residents following improvements implemented at the plant on December 10, 1997 is consistent with the observed improvements in raw and finished water quality parameters. The lack of an obvious spatial relationship between endemic gastroenteritis and water service area (using spatial regression) together with the lack of a significant temporal relationship between endemic gastroenteritis and finished water turbidity (using time series analysis), suggest that this apparent decrease in risk is minor, and the relationship tenuous. Nevertheless, the lack of an obvious decrease in the risk of endemic gastroenteritis following the improvements at the Rossdale plant despite marked improvements in raw water quality, together with the lack of an obvious spatial relationship among the service areas, further supports the effectiveness of the operation and treatment processes utilised in Edmonton.

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[1] Aramini, J., et al. 2000. Drinking water quality and health care utilisation for gastrointestinal illness in Greater Vancouver. Health Canada.

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SECTION 1: INTRODUCTION

1.1 Background

Contaminated municipal water supplies have been linked to numerous gastrointestinal outbreaks. Recent events in North America have highlighted the far-reaching impact of waterborne outbreaks on the community (Stirling et al, 2001; Grey Bruce Health Unit, 2000; MacKenzie et al, 1994). While outbreak investigations strive to estimate the health impact within a defined time interval, less is known about the effect of water quality on the endemic rate of illness within a community. Advances in analytical methodologies have enabled researchers to derive quantitative estimates of these impacts. By applying these techniques, several recent studies have identified links between water quality and endemic gastroenteritis (Aramini et al, 2000; Schwartz et al, 2000; Morris et al, 1998; Schwartz et al, 1997).

The current investigation is part of a series of national multi-centric studies being led by Health Canada to investigate risk factors and the burden of illness associated with drinking water. Since this investigation is an extension of the original study that was conducted in Vancouver (Aramini et al, 2000)[2], a detailed account of the historic background and rationale for this study is not repeated in this report. A comprehensive review of common waterborne pathogens and their associated risk to public health is also provided in the Vancouver report.

The Vancouver study identified strong relationships between drinking water quality (measured by the level of turbidity in the water received at home) and gastroenteritis. At the time of the investigation (1993-1998), filtration procedures were not part of the water purification process in Vancouver. The primary objective of this study was to apply similar methodologies to determine if Edmonton's municipal water supply influenced endemic gastroenteritis in Edmonton, between 1993 to 1998.

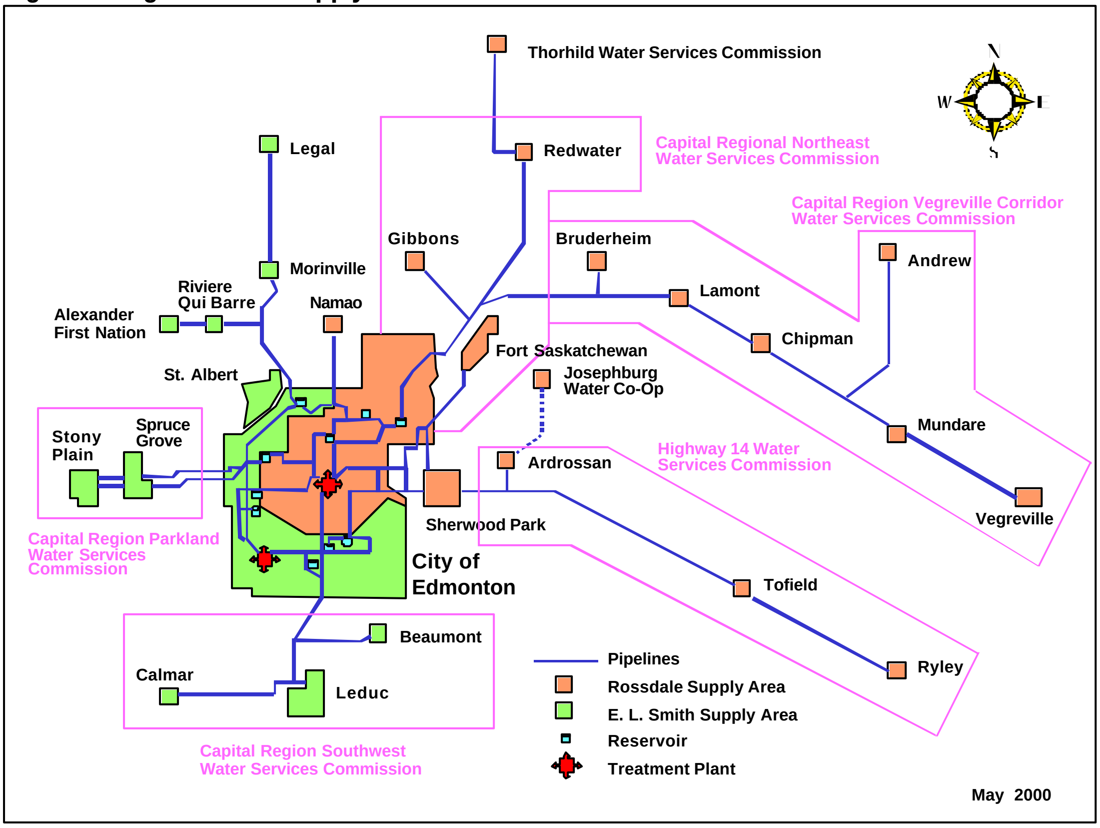
1.2 Edmonton's Water Supply

EPCOR Water Services Inc., which is a subsidiary of EPCOR Utilities Inc., supplies water to the city of Edmonton and its surrounding region. An extensive pipe distribution system spanning approximately 3100 kilometres enables access to more than 40 communities. Twelve reservoirs

[2] All subsequent references to Vancouver refer to this report

interspersed throughout the city have a total holding capacity of 808 million litres, which is equivalent to a three-day reserve supply. The majority of consumers within the city of Edmonton receive water within two days of leaving the water treatment facilities (per. comm., EPCOR). This distribution system is depicted in Figure 1.

Figure 1: Regional water supply in Edmonton



During the year 2000, EPCOR distributed water to 658,000 Edmonton residents, and 187,000 persons in surrounding communities. With a diverse portfolio, only half of the water consumption comes from residential and multi-family dwellings. Other consumer types include commercial, industrial, wholesale and regional users.

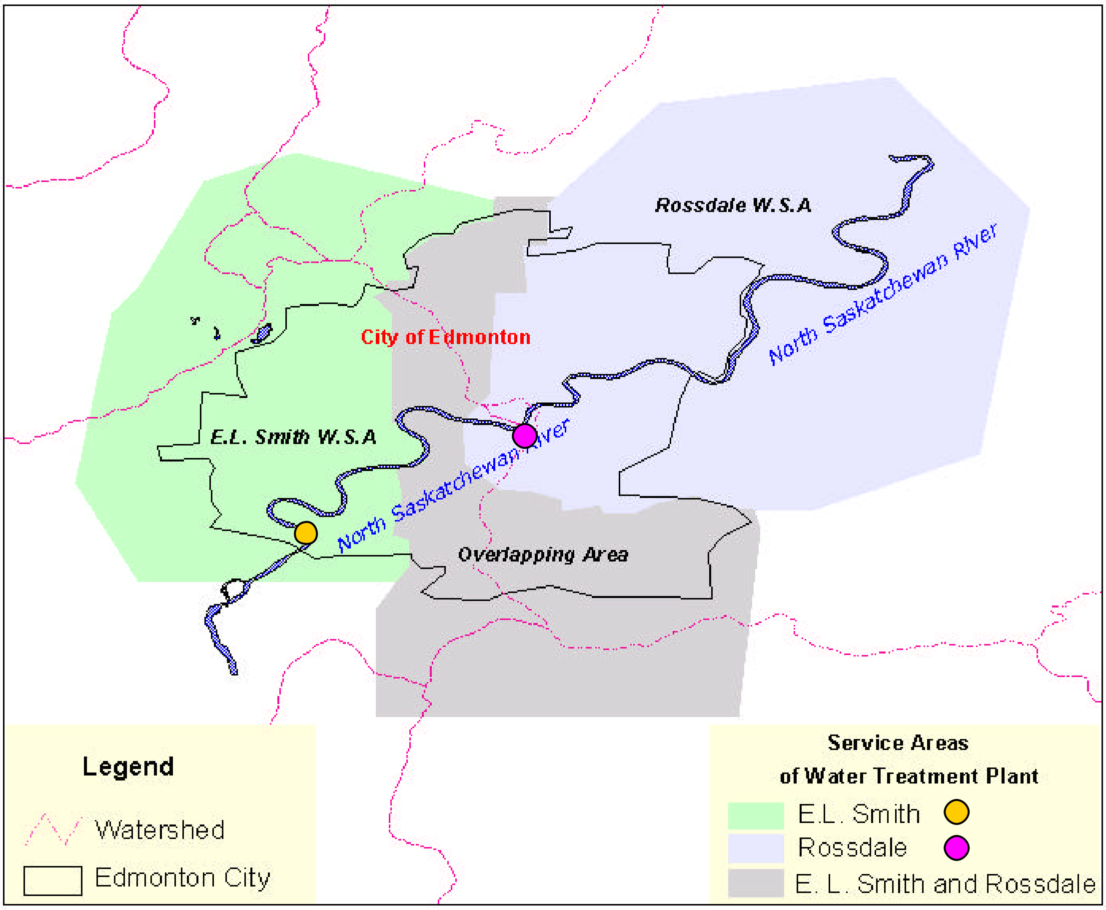
1.2 a) Water treatment plants

Edmonton and many of the surrounding communities in the region are serviced by two water treatment plants located within the city: the Rossdale plant and the E.L. Smith plant. Using Geographic Information Systems application software, (Arc View 3.2, Environment Systems Research

Institute, Inc.), water service areas for each plant were digitally mapped, and are shown in Figure 2. Regions where the water source could not be uniquely identified are shaded in grey.

The Rossdale plant consists of two treatment facilities – the first was built in 1947, and the second in 1956. Combined, they have the capacity to treat 275 million litres of water per day. The E.L. Smith plant was subsequently built in 1976 to meet the demands of an expanding population. With a treatment capacity of 240 million litres per day, this latter plant was built away from the downtown core, upstream of the Rossdale facilities. Both plants draw in water from the North Saskatchewan River, which is within the North Saskatchewan River Basin.

Figure 2: Water service areas for the Rossdale and E.L. Smith plants, Edmonton



1.2 b) Watershed characteristics

The North Saskatchewan River originates from the foot of the Columbia Icefields in the Rocky Mountains south-west of Edmonton, and flows directly through Edmonton. En route, the river is fed by numerous rivers and creeks.

In contrast to the watersheds that serve as Vancouver's water source, the North Saskatchewan River Basin is not protected from human and agricultural influences. Covering 28,000 square kilometres, this watershed contains mountains, forests, several communities and farm lands.

The upper half of the watershed is mountainous and forested, with little human activity. In contrast, the lower watershed is flatter, more inhabited, and supports agricultural activities. The watershed contains a thriving livestock industry, with approximately 290,000 cattle. It also supports an extensive wildlife population that includes deer, elk, beaver, and moose. Approximately 76,000 people reside in the upstream basin in a number of small towns and hamlets. Four continuous discharge sewage treatment plants and 16 sewage treatment lagoons discharge waste to the North Saskatchewan River upstream of the city of Edmonton. The continuous discharge sewage treatment plants utilise secondary treatment to process waste materials. There is limited industry in the upstream basin apart from forestry, and oil and gas extraction. This latter activity includes many pipelines that collect at refineries in Edmonton (per. comm., EPCOR).

The soils in the watershed are primarily glacial clays, and result in very high turbidities during high river flow situations. The mean yearly flow in the North Saskatchewan River is just over 200 m^3 per second, but peak flows can exceed 800 m^3 per second. The river has stable flows during the winter season under ice cover, but is susceptible to rapidly changing flows during the spring season when snowmelt and spring run-off situations occur. Heavy rainfalls during the summer also increase the river flow rate (per. comm., EPCOR).

1.2 c) Water purification procedures

The Rossdale and E.L. Smith plants utilise a multi-step approach to treat water drawn-in from the North Saskatchewan River. The process begins with intake pipes that draw-in water from the deepest part of the river. Screens at the end of these pipes prevent debris and fish from being drawn into the system. Coagulant chemicals are mixed with the raw water to achieve flocculation. During sedimentation, the aggregate particles settle to the bottom, and the clear water above is passed on to the next stage. Lime is then added, and the precipitated hardness is removed in a further sedmintation process. Carbon dioxide is added to reduce the pH after softening. Chlorine is added to the clarified water for disinfection, then ammonia is added to convert the remaining free chlorine to chloramine. Then the water is filtered through an almost 1-metre deep bed of fine anthracite coal and sand (E.L. Smith) or monomedia sand (Rossdale). Activated carbon is added during runoff periods to reduce the presence of organic material and to improve the taste and odour of the water. At the end of this process, the water is pumped out into the city to the customer, either directly, or through additional storage reservoirs located across the city.

1.3 Study Objectives

The primary objective of this investigation was to determine if endemic gastroenteritis within the city of Edmonton was influenced by the municipal water supply between January 1993 to December 1998. Using the level of turbidity in finished water as the primary measure of drinking water quality, a significant association was identified with endemic gastroenteritis in Vancouver. At the time of that investigation, filtration was not part of the water purification process in Vancouver. Other investigators have also found similar relationships using similar methodologies (Morris et al, 1998; Schwartz et al, 1997).

Geographic differences between the two Edmonton water treatment plants with respect to their point of access on the North Saskatchewan River warrant comparison in the levels of illness among their respectively serviced populations. The E.L. Smith plant is located upstream from the Rossdale plant, which in contrast, is situated in the downtown core (Figure 2). While the E.L. Smith plant is unaffected by city storm sewer runoff, the Rossdale plants are susceptible to runoff from 80 stormsewers upstream. In December of 1997, the Rossdale intake pipe was moved away from the shoreline towards the centre of the river in an attempt to minimise the impacts of stormsewer run-off on the quality of raw water. Concurrent with this event was the introduction of the use of particle counters at the plant, which allowed much better optimisation of the filters to minimise the effect of filter-to-waste periods, filter spikes, and particle increases at the end of filter runs.

Another objective of this investigation was to compare and contrast the utility of various water quality indicators for identifying potential relationships with gastroenteritis. In addition to finished water turbidity, particle counts in finished water were examined. Raw water indicators, such as turbidity and coliform counts, were also considered.

Finally, the effect of environmental parameters including temperature and precipitation were assessed. Heavy rainfall has been implicated as an inciting factor in several waterborne gastroenteritis outbreaks (Curriero et al, 2001; Grey Bruce Health Unit, 2000). In Edmonton, run-off potentially carries animal waste and irrigation chemicals into the North Saskatchewan River, which may then compromise the water purification process.

Achieving the objectives listed for this investigation allowed for an assessment of the nature of the relationship, if any, between Edmonton's municipal water supply and endemic gastroenteritis.

SECTION 2: DATA SOURCES

To assess the relationship between water quality and gastroenteritis, a comprehensive database was created from data that were provided by various agencies. Extensive retrospective water quality and environmental data were collected to assess their impact on community health. Data stemming from hospitalisation use and physician-billing claims were used to create appropriate health outcome groups. A description of these data are provided in the subsequent sections.

2.1 Water Quality Parameters

Water quality data from January 1, 1993 to June 30, 1999 were provided by EPCOR Water Services, Inc. A complete list of the types of data provided are listed in Table 1. With the exception of the particle count data, dates of availability for all the measured indicators are identical for both plants. However, data that were available for analysis differed for some parameters, depending on when automated data retrieval systems were implemented. Finished water turbidity was provided in the form of 5-minute readings for all on-line filters (nine in Rossdale, twelve in E.L. Smith). To facilitate analysis using these extensive data (288 readings per filter per day), these data were summarised into daily mean, median, and maximum values. Subsequent statistical tests were used to determine the optimal parameterisation for these data.

Compared to the Vancouver study, additional variables available for analysis in this investigation included finished water particle count data. The use of particle counts is a new approach to measuring water quality. Only recently implemented, particle counts are perceived to be a more accurate proxy measure of finished water quality than turbidity. Many of the raw water parameters listed in Table 1 were also unique to this investigation, and were not examined in the Vancouver study.

Table 1: Indicators of water quality received from EPCOR Water Services, Inc.

Water Quality Parameters	Provision Dates
Finished water	
* Turbidity	January 1 1993 to June 30 1999
* Particle Counts	
Rossdale plant	January 1, 1998 to June 30, 1999
E.L. Smith plant	March 13, 1998 to June 30, 1999
Raw water	
* Turbidity	January 1, 1993 to June 30, 1999
* Temperature	January 1, 1993 to June 30, 1999
* pH	January 1, 1993 to June 30, 1999
* Colour	January 1, 1993 to June 30, 1999
* Faecal coliform counts	January 1, 1994 to June 30, 1999
* Total coliform counts	January 1, 1994 to June 30, 1999

2.2 Environmental Parameters

Environmental parameters from January 1, 1993 to December 31, 1998 were provided by Environment Canada. Daily maximum and minimum temperatures in degrees Celsius, and daily precipitation measured in millimetres were used.

2.3 Socio-Economic Data

Average household income in 1995 was derived from the 1996 Census Data (Statistics Canada).

2.4 Health Outcome Data

Emergency visit data and hospitalisation admission data have been used previously to assess endemic gastroenteritis (Morris et al, 1998; Schawrtz et al, 1997). Many similarities exist between the health outcome data utilised in the Vancouver study and the current study. In the Vancouver study, a total of three different sources were used: hospitalisation admission data from the Canadian Institute for Health Information (CIHI); physician visit data from the Medical Services Plan in B.C.; and emergency room visit data from the British Columbia Childrens' Hospital. A comparison was then made among these datasets to determine consistency of results.

In the present study, two primary data sources were used: hospital admission data from CIHI; and physician-billing data from the Alberta Health Care Insurance Payment Plan. However, in contrast to the Vancouver study, it was possible to further differentiate the latter data source into three distinct categories: namely, billing that resulted from emergency room visits, physician-office visits, and long-long-term care facilities. Recognising that the various data-capture-sources would be more representative of certain populations, interpretations of the results were based on the findings from each of the four different data sources. The selection criteria for gastrointestinal cases and respiratory controls were based on the literature (Morris et al, 1998; Schwartz et al, 1987) and on the advice of general practitioners and a gastroenterologist.

2.4 a) Canadian Institute for Health Information

The Canadian Institute for Health Information receives data from approximately 85% of hospitals across Canada. Each record within this comprehensive database contains the specifics of each case admission, including the patient's date-of-birth, gender, postal code of residence, scrambled personal identifier, admission date, reason for admission, surgery type, diagnosis fields, and institute type. Only valid and complete records from January 1, 1993 to December 31, 1998 were further considered for the case and control selection process. These criteria selected patients that had a valid date-of-birth, admission date, and gender information. A postal code was also required to verify residence within Edmonton. Elective surgeries and elective admissions to acute care facilities were excluded from further investigation.

Gastrointestinal cases and respiratory controls were selected using a similar approach to that described in the Vancouver study. The 9th revision of the International Classification of Diseases (ICD-9), published by the World Health Organisation, is designed for the classification of morbidity and mortality information for statistical purposes, and for the indexing of hospital records by disease and operations, for data storage and retrieval. Appropriate 3-digit and 4-digit ICD-9 codes were selected to designate admitted patients as gastroenteritis cases or respiratory controls.

Criteria for selecting gastroenteritis cases are outlined in Table 2. A **gastroenteritis case** was defined as any individual with a primary diagnosis[3] of one of the ICD-9 codes marked in column A, or with a primary diagnosis of one of the ICD-9 codes marked in column B and a secondary diagnosis of one of the ICD-9 codes marked in column A.

Table 2: Criteria for selecting hospital admission gastroenteritis cases in the CIHI data source

		Case Definition 1	Case Definition 2		
ICD-9	**Description**	**Column A: 1º diagnosis**	**Column B: 1º diagnosis**	**with**	**Column A: 2º diagnosis**
001	Cholera	X			X
002	Typhoid and paratyphoid fevers	X			X
003	Other salmonella infections	X			X
004	Shigellosis	X			X
005	Other food poisoning (bacterial)	X			X
006	Amoebiasis	X			X
007	Other protozoal intestinal diseases	X			X
008	Intestinal infections due to other organisms	X			X
009	Ill-defined intestinal infections	X			X
558*	Other noninfectious gastroenteritis and colitis	X			X
5350	Acute gastritis	X			X
5354	Other gastritis	X			X
5355	Unspecified gastritis and gastroduodenitis	X			X
5356	Duodenitis	X			X
5589	Other and unspecified noninfectious gastroenteritis and colitis	X			X
7870	Nausea and vomiting	X			X
276	Disorders of fluid, electrolyte, and acid-base balance		X		
787	Symptoms involving digestive system		X		
5781	Melaena		X		
6910	Diaper or napkin rash		X		
7806	Pyrexia of unknown origin		X		
7830	Anorexia		X		
7832	Abnormal loss of weight		X		
7890	Abdominal pain		X		

* Although labelled as "noninfectious", may in fact be an undiagnosed episode of infectious gastroenteritis

[3] Defined as the most significant contributor to the hospital stay

Criteria for selecting respiratory controls are outlined in Table 3. A **respiratory control** was defined as any individual with a primary diagnosis of one of the ICD-9 codes marked in column C and without an additional diagnosis of any of the ICD-9 codes marked in column D.

Table 3: Criteria for selecting hospital admission respiratory controls in the CIHI data source

ICD-9	Description	Column C: 1° diagnosis	without	Column D: 1° or 2° or 3° diagnosis
460	Acute nasopharyngitis	X		
461	Acute sinusitis	X		
462	Acute pharyngitis	X		
463	Acute tonsillitis	X		
464	Acute laryngitis and tracheitis	X		
465	Acute upper respiratory infections of multiple or unspecified sites	X		
466	Acute bronchitis and bronchiolitis	X		
480	Viral pneumonia	X		
481	Pneumococcal pneumonia	X		
482	Other bacterial pneumonia	X		
483	Pneumonia due to other specified organism	X		
484	Pneumonia in infectious disease classified elsewhere	X		
485	Bronchopneumonia, organism unspecified	X		
486	Pneumonia, organism unspecified	X		
487	Influenza	X		
490	Bronchitis, not specified as acute or chronic	X		
491	Chronic bronchitis	X		
492	Emphysema	X		
493	Asthma	X		
494	Bronchiectasis	X		
496	Chronic airway obstruction, not elsewhere classified	X		
001	Cholera			X
002	Typhoid and paratyphoid fevers			X
003	Other salmonella infections			X
004	Shigellosis			X
005	Other food poisoning (bacterial)			X
006	Amoebiasis			X
007	Other protozoal intestinal diseases			X
008	Intestinal infections due to other organisms			X
009	Ill-defined intestinal infections			X
041	Bacterial infection in conditions classified elsewhere			X
027	Other zoonotic bacterial diseases			X
070	Viral hepatitis			X
276	Disorders of fluid, electrolyte, and acid-base balance			X
520-579	Diseases of the digestive system			X
787	Symptoms involving digestive system			X
789	Other symptoms involving abdomen and pelvis			X

To prevent over-estimating the rate of illness and thus distorting the true relationship between gastroenteritis and water quality for both cases and controls, admissions with a similar diagnosis which occurred within 60 days of an initial visit were considered part of the same disease episode, and thus were not included in the analysis.

2.4 b) Alberta Health Care Insurance Payment Plan

The Alberta Health Care Insurance Payment Plan (AHCIPP) maintains a comprehensive database on all billing claims that originate from a variety of health care provider types. As with the CIHI database, each record within the AHCIPP database contains patient-specific information, including the age at time of treatment, gender, postal code of residence, scrambled personal identifier, diagnosis fields, and coded aggregate function centre type. This last field was used to differentiate between claims originating from various sources. Billing resulting from emergency room visits (EMRG), physician-office visits (PHYS), and long-term care centres [4] (LTC) were analysed separately

Within each of these three data sources, records from January 1, 1993 to December 31, 1998 with a valid age, gender, and postal code within Edmonton were selected. Since only 3-digit ICD-9 codes were available in the AHCIPP database, the criteria used to select cases and controls varied slightly from the CIHI database. For these data, a **gastroenteritis case** was defined as an individual who was diagnosed with an intestinal infectious disease (ICD-9 codes: 001-009, refer to Tables 2 and 3) or other "noninfectious" gastroenteritis and colitis (558). A **respiratory control** was defined as an individual who was given a primary diagnosis of an acute respiratory infection (460-466), pneumonia (480-483, 485-486), or asthma (493), who did not also suffer from an intestinal infectious disease (001 to 009), disease of the digestive system (520 to 579), nor any of the other gastrointestinal-related illness described in Table 3 (027, 041, 070, 276, 487, 787, 789). All repeat visits within a 60-day interval were excluded.

2.5 Assigning a Primary Water Source

As in the Vancouver study, water received at home was chosen as the primary exposure variable of interest. Therefore, to identify potential associations between water quality and

[4] Long-term care centres provide regular treatment services and continuing care to seniors, as well as those with persistent mental illness and physical disabilities.

gastroenteritis, the same method of assigning cases and controls to their primary water source was used. The 6-digit postal codes provided in the health outcome data were linked to a digitised postal code file (Enhanced Postal Code File, Desktop Mapping Technologies, Inc.). This procedure designates a centroid point, along with geographical co-ordinates, for each postal code region. Applying GIS overlay techniques on the digitally-mapped water service areas shown in Figure 2, Edmonton residents were linked to a primary water source based on their location of residence.

SECTION 3: INVESTIGATIVE METHODS

3.1 Descriptive Analyses

Descriptive analyses were carried out initially to identify general trends and associations in both the health outcome and exposure data. Temporal trends in the health outcome data were investigated and a profile of each data source was created to determine the proportion of cases within each age group and for each water service area. The distributions of primary ICD-9 codes captured in the case definition were also determined. Preliminary statistics were determined for the water quality and environmental parameters. Comparisons were made between the two water treatment plants to determine if general differences in water quality existed.

3.2 Multivariate Logistic Regression

3.2 a) Methodology overview

The primary objective of this portion of the analysis was to compare the risk of gastroenteritis for residents within each of the water service areas in Edmonton. Results from the descriptive analyses demonstrated that some differences in water quality existed between the two water treatment plants. All individuals with a valid Edmonton postal code who could be linked to the Rossdale or E.L. Smith water service areas, as well as individuals residing in the mixed zone, were included in this portion of the analysis. Infants (< 2 years) were excluded from this investigation since it was hypothesised that their intake of tap water in the home was likely minimised due to neonatal feeding practices, and thus not compatible with the remaining study population with respect to exposure patterns.

A case-control study design was used for this analysis. The modeled binomial response was case status: gastroenteritis case or respiratory control. Respiratory controls were used to help control for the potential influences of environmental factors on health outcome. The effect of modeled variables on health outcome was given by odds ratios. Each health outcome data set for the multivariate logistic regression portion of the analysis contained binary health outcomes, and each data set was modeled independently. The components of these analyses are summarised in Table 4.

Table 4: Components of the analytic approaches utilised in the multivariate logistic regression analyses

Analysis	Modeling Approach	Modeled outcome	Study population	Health outcome data sets separated by Data source
Multivariate Logistic Regression	Generalised Linear Model (GLM)	Binomial: gastroenteritis case or respiratory control	Defined cases and controls within Edmonton, in the Rossdale, E.L. Smith, or Mixed zone water service areas	CIHI (hospital admissions)
				EMRG (emergency-room visits)
				PHYS (physician office visits) (1 case:3 controls)
				LTC (long-term care visits)
	Spatial Generalised Additive Model (GAM)	Binomial: gastroenteritis case or respiratory control	Defined cases and controls within Edmonton, in the Rossdale, E.L. Smith, or Mixed zone water service areas	CIHI (hospital admissions)
				EMRG (emergency-room visits)
				PHYS (physician office visits) (1 case:1 control)
				LTC (long-term care visits)

Generalised Linear Models (GLM)

A generalised linear model (GLM) with a binomial distribution and logit link, was the underlying statistical model used to analyse these data (McCullagh and Nelder, 1983). The resulting multivariate logistic modeling process was carried out using the GENMOD procedure in SAS, version 8.0. Separate models were evaluated for each of the four health outcome data sources.

Due to the enormity of the data originating from the physician-office billing data source, a random subset of the data was taken to facilitate analysis. A 1:3 ratio of cases to controls was formed by randomly selecting 20% of original cases. This randomised selection process was carried out using a random number function (RANUNI) in SAS, version 8.0.

Spatial Generalised Additive Models (GAM)

Spatial regression models were subsequently carried out to provide a visual representation of the geographic differences in risk of gastroenteritis within the city of Edmonton. A binomial generalised additive model (GAM) was utilised to analyse the same health outcome data (Hastie and Tibshirani, 1990). GAM models are an extension of GLM models, in that a flexible additive non-linear relationship may be modeled between the independent predictor (risk factor) and the response. The response is modeled as a sum of smooth functions in the predictors, where these functions are estimated using smoothers (a curve is fit to the data points locally, so that at any point, the curve depends only on the observations at that point, and some specified neighbouring points – this estimate of the response is referred to as a smooth, and procedures for producing such fits are called smoothers). Model fit is improved through the flexible parameterisation of variables in GAM models, and parameter estimates may be derived with greater accuracy.

GAM models were used for this spatial component of the analysis to accommodate for the inclusion of geographical co-ordinates in the modeling process. The location of cases and controls was determined by using their corresponding 6-digit residential postal code. Longitude and latitude co-ordinates assigned to the centroid point within each postal code area were incorporated into the loess smoothing function within the GAM model (Cleveland and Devlin, 1988). This method of fitting the location effect directly into the statistical model as a non-linear parameter has also been applied in other studies where the objective has been to detect spatial clusters (Preisler et al, 1997; Brillinger, 1994; Chambers and Hastie, 1992; Cook and Pocock, 1983). The gam function in SPLUS 2000, release 2 (MathSoft, Inc.) was used to carry out this spatial component of the multivariate logistic regression analysis, as smoothing functions are easily accommodated in this analytical software package.

Similar to the GLM analysis, a random subset consisting of 20% of the original cases captured in the physician-office data source was created. Due to the computational intensity associated with fitting a loess smoother to the geographical co-ordinates, controls were selected to satisfy a 1:1 ratio of cases to controls using the same procedure described in the previous section.

3.2 b) Variables analysed

A list of variables investigated in both of the multivariate logistic regression processes is provided in Table 5.

Generalised Linear Models (GLM)

To estimate the risk of gastroenteritis for residents within each of the water service areas, a categorical variable was created to reflect the primary water source in the generalised linear modeling. Levels of this variable, SOURCE were:

- Mixed zone, before December 10, 1997
- Mixed zone, after December 10, 1997
- Rossdale water service area, before December 10, 1997
- Rossdale water service area, after December 10, 1997
- E.L. Smith water service area, before December 10, 1997
- E.L. Smith water service area, after December 10, 1997

Table 5: Independent variables analysed for the multivariate logistic regression analyses

Analysis	Modelling Approach	Variable Name	Description
Multivariate Logistic Regression	Generalised Linear Model (GLM)	SOURCE	Categorical term to denote primary water source
		SPLINES1…37	Seaonal parameter using splines to represent each 2-month interval
		INCOME	Average household income in 1995 per postal code
		AGEGROUP	Categorical variable: 2 to 18 yrs, > 18 to 65 yrs,> 65 yrs
	Spatial Generalised Additive Model (GAM)	LONGITUDE, LATITUDE	Spatial term using longitude and latitude , smoothed term
		DEC1097	Categorical term to denote before and after December 10, 1997
		SEASON	Seasonal parameter using 220-day cycle, smoothed term
		INCOME	Average household income in 1995 per postal code
		AGEGROUP	Categorical variable: 2 to 18 yrs, 18 to 65 yrs,> 65 yrs

The risks associated with each of the water service areas were distinguished between when the Rossdale intake pipe was moved, which coincided with the introduction of particle counters in this plant (December 10, 1997). This distinction was made since raw water quality from the Rossdale plant changed following these events. Statistical comparisons in risk among SOURCE levels were carried out using contrasts. Since residential location is a reflection of the quality of water received at home, none of the water quality nor environmental parameters associated with the time series analysis were included in these analyses.

Since SAS does not easily accommodate loess smoothing functions in regression models, a separate spline was created for each 2-month period, so that different slopes (risk estimates) could be determined for each time interval, and thus control for seasonal trends in viral gastroenteritis. This technique is used when it can be expected that the effects vary across different levels of a variable. Comparisons between models using splines in SAS and the loess smoothing function in S-PLUS to adjust for seasonal trends, produced similar results (data not provided).

Household income was used as an indicator of socio-economic status, which was hypothesised to influence the risk of illness. The average household income reported in 1995 for each enumeration area (Statistics Canada, 1996) was linked to each postal code, and subsequently to each case and control. This variable was included in all models.

Age was fit as a categorical variable in these models to adjust for potential differences in risk between age groups. Thus, an averaged estimate of risk for residents of different water service areas was obtained. Categories for age were identical to the levels of stratification used in the time series analysis: 2 to 18 years, greater than 18 to 65 years, and greater than 65 years.

Spatial Generalised Additive Models (GAM)

A loess smoother was fit to the longitude and latitude co-ordinates of the centroid points for each postal code. This independent (risk factor) variable was used to derive estimates of the risk of gastroenteritis for various locations within Edmonton. A categorical term, DEC1097 was also modeled to represent the risk prior to and after the relocation of the Rossdale intake pipe. The inclusion of these variables in the spatial model replaced the categorical term SOURCE used in the GLM modeling process.

Since S-PLUS easily accommodates smoothing functions, seasonal fluctuations in gastroenteritis were also modeled using the loess smoothing function. Average household income and age were also included in these spatial models.

3.2 c) Criteria for model-selection

For the GLM models, step-wise model selection based on the variables listed in Table 5 was conducted for each health outcome data set. The effect of each variable was evaluated by using the likelihood ratio test (Fahrmeir and Tutz, 1994). Criteria for inclusion in the final model was set at the 5% level of statistical significance. Model-fit was examined using Akaike's Information Criterion (Sakamoto et al, 1986). Variables in the spatial model (GAM) were chosen to reflect the variables identified in the final multivariate logistic regression model.

3.3 Time Series Analysis

3.3 a) Methodology overview

Similar to the Vancouver study, generalised additive models (GAM) were used to investigate temporal relationships between water quality and gastroenteritis. This approach has also been applied in other time series studies (Morris et al, 1998; Schwartz et al, 1997). The application of this methodology for time series investigations has been described in detail in the Vancouver study (Aramini et al, 2000). S-PLUS 2000, release 2 (MathSoft, Inc.) was used to carry out this portion of the analysis.

A loess smoothing function (Cleveland and Devlin, 1988) was used to describe the potentially non-linear relationship between the risk of gastroenteritis and turbidity, along with other water quality and environmental parameters described in sections 2.1 and 2.2. In addition, the smoothing function was also applied to fit a seasonal (long-term) parameter in an attempt to control for seasonal trends in gastroenteritis. A 220-day cycle, which was employed and described in the Vancouver study, was used to represent this seasonal trend.

To determine the influence of water quality from each plant on the corresponding serviced population, individuals from each of the four data sources were analysed separately, based on the primary water source. Individuals whose primary water source could not be uniquely identified (mixed zone - shaded grey area in Figure 2) were excluded from this analysis. By matching the date of health event to the date of the recorded water quality parameter, daily water quality values observed for each plant were then linked to the appropriate individuals.

As explained in the Vancouver study, both binomial (case-control) and poisson GAM models (Hastie and Tibshirani, 1990) were fit to the data. In the binomial models, the modeled outcome was case status: gastroenteritis case or respiratory control. The outcome for the poisson models was daily count of gastroenteritis cases. The effect of modeled variables on gastroenteritis was given by odds ratio and relative risks for the binomial and poisson models, respectively.

Since susceptibility to illness varies across different age groups, separate analyses were conducted for each of the following age groups: 2 to 18 years, greater than 18 to 65 years, and greater than 65 years. These age groups are identical to those used in the Vancouver study, with the exception that infants (< 2 years) were excluded from this investigation. Therefore, each health outcome data set used in this analysis was specific to each age group, water service area, and data source (refer to Table 6).

In the binomial analysis, a randomised subset of cases and controls were selected from the physician-office data, using a 1:3 ratio of cases to controls. This was the same subset described in the GLM modeling approach. Physician-office data were not reduced for the poisson analysis since gastrointestinal outcomes were collapsed into daily counts, and the resulting smaller data set was therefore easily processed by the software application.

Table 6: Components of the analytic approaches utilised in the time series analysis

Analysis	Modeling Approach	Modeled outcome	Study population	Health outcome data sets separated by		
				Data source	Age group	Plant
Time Series Analysis	Generalized Additive Model (GAM)	Binomial: gastroenteritis case or respiratory control	Defined cases and controls within Edmonton, in the Rossdale or E.L. Smith water service areas only	cihi	2 to 18	Rossdale
				emrg	> 18 to 65	
				phys (1:3)	> 65	E.L. Smith
				ltc		
		Poisson: daily counts of gastroenteritis cases	Defined cases within Edmonton, in the Rossdale or E.L. Smith water service areas only	cihi	2 to 18	Rossdale
				emrg	> 18 to 65	
				phys	> 65	E.L. Smith
				ltc		

3.3 b) Variables analysed

A list of the independent (risk factor) variables assessed in the time series analysis is provided in Table 7. Time series variables that were lagged are denoted with subscript i. A description of some of the key variables is provided below.

Separate analyses were conducted for each time series health outcome data set. For the water quality and environmental parameters, values from 0 to 40 days prior to the day of the health outcome event were modeled. This range of lagged values was selected to reflect multiples of the incubation periods commonly reported for prevalent waterborne pathogens. Therefore, for each time series health outcome data set and combination of variables analysed, 41 models were evaluated (one for each lag day).

Finished water turbidity (TB) was the primary variable of interest for this analysis. However, the effects of other water quality parameters were also evaluated. Five-minute readings that were provided for some of the water quality parameters were summarised as daily observed values, including the mean, median, and maximum reading for that day. Statistical comparisons among models with the various parameterisations of these data, indicated that the daily mean provided the best fit to the data. Therefore, all 5-minute readings were summarised as daily means. Rare occurrences of missing values, which were occasionally the result of off-line filters, were replaced with the mean of adjacent observed values.

Table 7: Independent variables analysed for the time series analysis

Analysis	Modeling Approach	Variable Name	Description
Time Series Analysis	Generalised Additive Model (GAM)	TBi	Finished water daily mean turbidity, smoothed term
		PCi	Finished water daily mean particle counts, smoothed term
		RAWFCi	Raw water daily fecal coliform counts, smoothed term
		RAWTCi	Raw water daily total coliform counts, smoothed term
		RAWTBi	Raw water daily mean turbidity, smoothed term
		RAWTEMPi	Raw water daily temperature, smoothed term
		RAWPHi	Raw water daily ph, smoothed term
		RAWCOLi	Raw water daily mean colour index, smoothed term
		TMAXi	Maximum daily mean atmospheric temperature, smoothed term
		TMINi	Minimum daily mean atmospheric temperature, smoothed term
		PRECIPi	Daily mean precipitation, smoothed term
		SEASON	Seasonal parameter using 220-day cycle, smoothed term
		DOW	Day of week (1-7)
		HOLIDAY	Statutory holiday and adjacent days

Environmental parameters were also examined. In addition to the effect of weather on raw water turbidity, precipitation was also hypothesised to influence the level of exposure at home. It was hypothesised that people are more likely to stay indoors as a result of inclement weather, facilitating person-to-person spread of infectious gastroenteritis. Therefore, precipitation and temperature lagged up to 40 days prior to the day of the health outcome event were similarly investigated.

Temporal confounders were included in the models to adjust for temporal variations, including the seasonal parameter. Day-of-week effects were significant in the Vancouver study and were similarly included in this study. Statutory holidays were also considered to determine if changes in the accessibility of medical services, as well as holiday behaviours, had an impact on gastroenteritis. To that end, separate categories were created for the following holidays and holiday weekends: Christmas and New Year's, Easter, Victoria Day, Canada Day, August Long Weekend, Labour Day, Thanksgiving, and Remembrance Day. In addition, the week following each holiday event was also assessed (with the exception of Remembrance Day).

Finally, an autoregressive term was included in all of the models to adjust for the correlation arising from daily observations made of each health outcome event. As discussed in the Vancouver study, even in the absence of a relationship with water quality, the number of hospital admissions, physician visits, emergency room visits, and treatments provided in a long-term care facility on any given day can be expected to be related to the number the day before. Several possible reasons for this include persons sharing a common food or water source, and variable pathogen incubation times. The autoregressive term was expressed as a ratio of the number of cases to the number of controls, and was fit as a linear term in the model.

3.3 c) Criteria for model-selection

Based on the descriptive analyses and on the multivariate logistic regression results, quantitative time series analysis was conducted for the water service area that represented the highest potential risk of endemic waterborne gastroenteritis (Rossdale, prior to December 10, 1997). Similar to the multivariate logistic regression, the effect of each variable listed in Table 7 was determined by conducting deviance comparisons using the likelihood-ratio test, and comparing AIC values and parameter estimates. Significant lags were identified by comparing the change in deviance in models with and without the lagged variable, thereby evaluating the overall effect of that lagged variable. However, multiple statistical comparisons increase the probability of erroneously detecting a statistically significant association, commonly referred to as Type I error (Steel et al, 1997). Therefore, when evaluating the effect of parameters up to 40 days prior to the health outcome event, only lags that were significant over two to three consecutive days were further assessed for consistency among the different age groups and health outcome data sources.

SECTION 4: RESULTS

4.1 Descriptive results

4.1 a) Water quality parameters

Summary statistics for the finished and raw water quality parameters of primary interest are provided in Table 8. Because of the changes that were implemented at the Rossdale plant on December 10, 1997 (movement of the intake pipe and the introduction of particle counters), results for this plant are further differentiated as prior to and following this event.

In general, raw water parameters indicate better quality of water entering the E.L. Smith plant in comparison to the Rossdale plant, both before and after December 10, 1997 (Table 8). The differences are most pronounced in total and faecal coliforms. Following December 10, 1997, the differences in raw water parameters between the plants are less prominent.

Of primary interest in the time series analysis was the daily finished water turbidity (TB_f). Prior to December 10, 1997, finished water turbidity values (mean and median) were slightly lower in the E.L. Smith plant (Table 8). Following December 10, 1997, summary statistics appeared to be equivalent. Limited data on particle counts in finished water were provided. Mean and median particle counts from the E.L. Smith plant are marginally lower. However, these data must be interpreted with caution, since they were only available in 1998.

Temporal trends for finished water parameters are further described in Figures 3a and 3b. These data have been presented using the loess smoother and a span appropriate to the data to reduce the 'noise' resulting from daily fluctuations in the data. These figures demonstrate that finished water turbidity values for the Rossdale experienced greater fluctuations (within 0.2 NTU) than those originating from the E.L. Smith plant. There is some suggestion, however, that following December 10, 1997, values became more stabilised.

For both plants, seasonal peaks in raw water turbidity during the summer months were apparent, and were likely due to an increase in run-off from rainfall. Faecal coliforms also appeared to favour these temperate months, as their numbers increased during this time.

Table 8: Summary statistics for indicators of raw and finished water quality: Jan. 1, 1993 to Dec. 31, 1998

Water Quality Data	Range			Std. Dev.	Median	Mean	95% Confidence Interval (Mean)
Finished water parameters							
* Daily mean turbidity (NTU)							
E.L. Smith	0.02	to	0.17	0.01	0.03	0.04	(0.039 , 0.040)
Rossdale	0.00	to	0.38	0.03	0.05	0.06	(0.059 , 0.061)
Before December 10, 1997[1]	0.00	to	0.38	0.03	0.05	0.06	(0.059 , 0.062)
After December 10, 1997[2]	0.02	to	0.07	0.01	0.04	0.04	(0.039 , 0.041)
* Daily mean particle counts, 1998 (counts per mL, (>2µm))							
E.L. Smith[3]	1.2	to	62.2	7.1	7.9	9.3	(8.5 , 10.1)
Rossdale[4]	2.5	to	55.3	7.3	12.5	13.3	(12.5 , 14.1)
Raw water parameters							
* Daily mean turbidity (NTU)							
E.L. Smith	0	to	1,967	98	6.0	31	(26.9 , 35.1)
Rossdale	1.1	to	1,754	101	8.0	34	(29.7 , 38.3)
Before December 10, 1997[1]	1.6	to	1,481	94	9.0	35	(30.7 , 39.3)
After December 10, 1997[2]	1.1	to	1,754	126	5.2	34	(21.5 , 46.5)
* Daily faecal coliform counts[5] (counts per 100mL)							
E.L. Smith	0	to	510	58	5	30	(28.0 , 32.0)
Rossdale	0	to	15,000	951	160	399	(353.9 , 444.1)
Before December 10, 1997[1]	0	to	15,000	1,052	200	480	(425.1 , 534.9)
After December 10, 1997[2]	0	to	2,800	188	51	96	(76.4 , 115.6)
* Daily total coliform counts[5] (counts per 100mL)							
E.L. Smith	0	to	3,800	404	40	133	(115.4 , 150.6)
Rossdale	0	to	346,000	15,886	2,100	6,221	(5,491.9 , 6,950.1)
Before December 10, 1997[1]	0	to	346,000	17,571	3,200	7,717	(6,809.5 , 8,624.5)
After December 10, 1997[2]	2	to	21,000	1,674	265	640	(473.4 , 806.6)

[1] Rossdale intake pipe relocated on December 10, 1997, at which time, particle counters were also introduced. Therefore, presented results are based on data up to and including December 10, 1997

[2] Presented results are based on data from December 11, 1997 and beyond

[3] Data available March 13 – December 31, 1998

[4] Data available January 1 - December 31, 1998

[5] Data available January 1, 1994– December 31, 1998