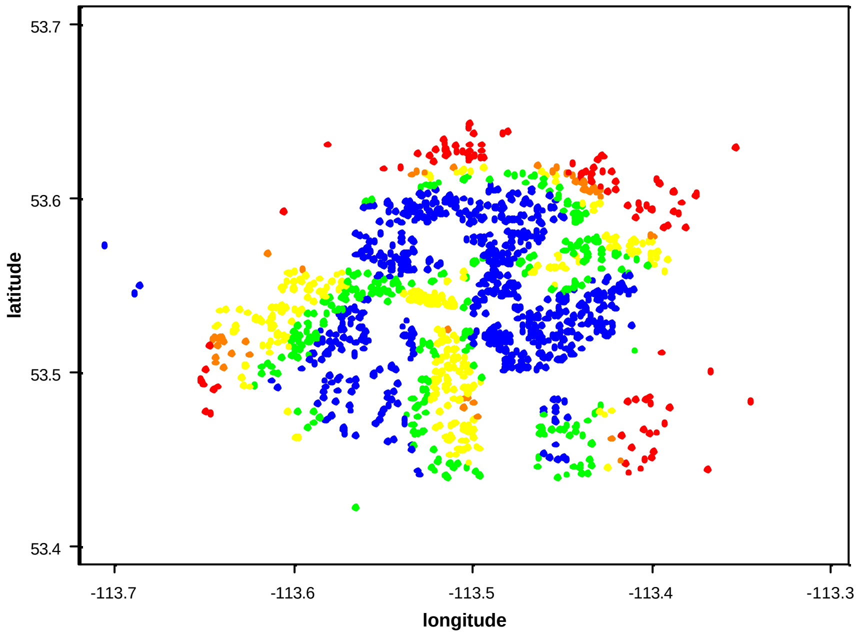
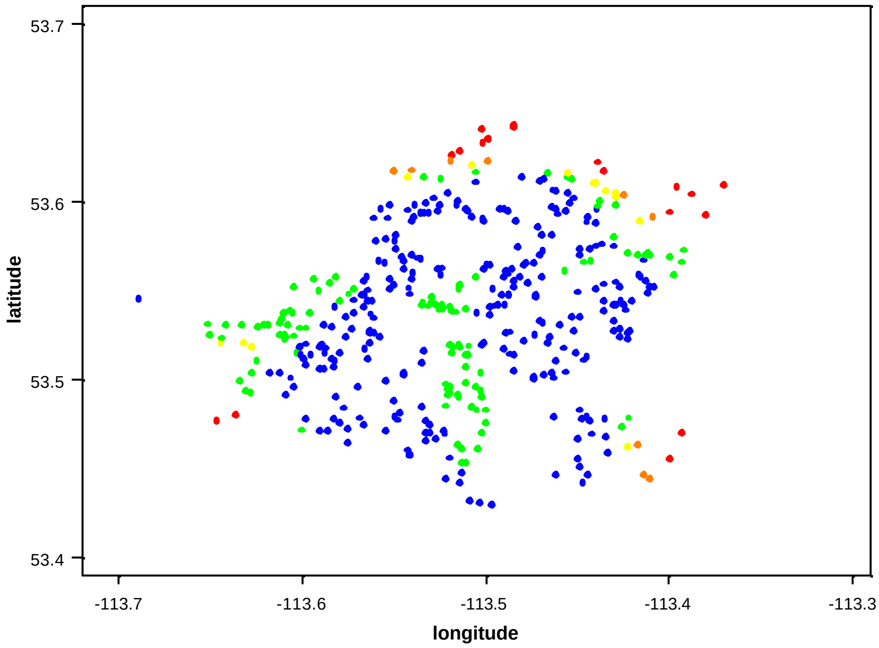
Figure 12d: Spatial distribution of disease risks within the city of Edmonton between 1993-1998: Long-term care data source, excluding infants (less than 2 year-olds)

(i) Prior to December 10, 1997



(ii) After December 10, 1997



Odds Ratios

< 1.0	1.0 – 1.1	1.1 – 1.2	1.2 – 1.3	> 1.3

4.2 b) Time series analysis

Based on the findings of the descriptive and multivariate logistic regression analyses, time series analysis was conducted only on individuals that resided within the Rossdale water service area. In addition, only water quality data prior to December 10, 1997 were analysed. Individuals supplied with Rossdale water prior to this date were more likely to be at the greatest potential risk of endemic waterborne gastroenteritis.

Using these data, final models for all time series health outcome data sets were derived using binomial and poisson analyses.

Poisson model:

Log(Counts) = loess (TB_{1-40}, span=0.95) + DOW effect + HOLIDAY effect + AR term + loess (Seasonal parameter, span=220 days)

Binomial model:

Logit(Case/Control) = loess (TB_{1-40}, span=0.95) + AR term + loess (Seasonal parameter, span=220 days)

(refer to Table 7 for a complete description of variable names)

From these final models, no significant finished water turbidity lags were identified using the criteria outlined in section 3.3c. Similarly, none of the other measured water quality and environmental parameters, including raw water quality parameters and precipitation, were significantly associated with endemic gastroenteritis.

Although no relationship with finished water turbidity was identified in this time series analysis, 3-D surface plots were constructed to facilitate a comparison to what was observed in the Vancouver study. Figures 13a to 13d show the estimated relative rates (Poisson model) and odds ratios (Binomial model) in the final model for lagged daily mean finished water turbidity values. Interpretation for relative rates are similar to that described for odds ratios in the previous section. That is, a relative rate of 1.2 represents a 20% increase in the likelihood of gastroenteritis associated with that level of turbidity for that particular lag, compared to the predicted probability associated with the mean turbidity effect for that particular lag, after adjusting for other parameters in the model. Estimates for the binomial model using the physician-visit billing data are based on a randomised subset of the original data (refer to Section 3.3a), since the software application that was used to analyse these data (S-PLUS 2000, release 2; Mathsoft, Inc.) could not manipulate the original extensive database. Only results from the greater than 65 year-old age group were presented for the long-term care data source since model estimates were highly unstable as a result of the limited data available for analysis in the other age groups.

Colour schemes in these figures are identical to those used in the Vancouver study. Results of point-wise comparisons for each lag and turbidity value were differentiated by the level of statistical significance. Red indicates that a point-wise relative rate or odds ratio was significantly greater than 1.0 (i.e. significantly greater than the average turbidity effect) at the 5% level of significance; yellow indicates significance at the 10% level. The turbidity scale was truncated to exclude days with turbidity values that were greater than the 95th percentile and therefore observed less than 5% of the time. Model estimates for these values were extremely unstable due to the limited data available for analysis, and the correspondingly large standard errors did not provide reliable statistical results.

Although sporadic statistical associations were observed in these 3-D plots, the primary statistical criterion used for identifying significant lags was determined using the likelihood ratio test (Fahrmeir and Tutz, 1994). And, as already stated, no significant lags were identified using this criterion. Furthermore, no consistent patterns could be appreciated among the 3-D plots.

Figure 13a: 3-D time series surface plots of disease risk within the Rossdale water service area between February 10, 1993 to December 10, 1997: CIHI data source

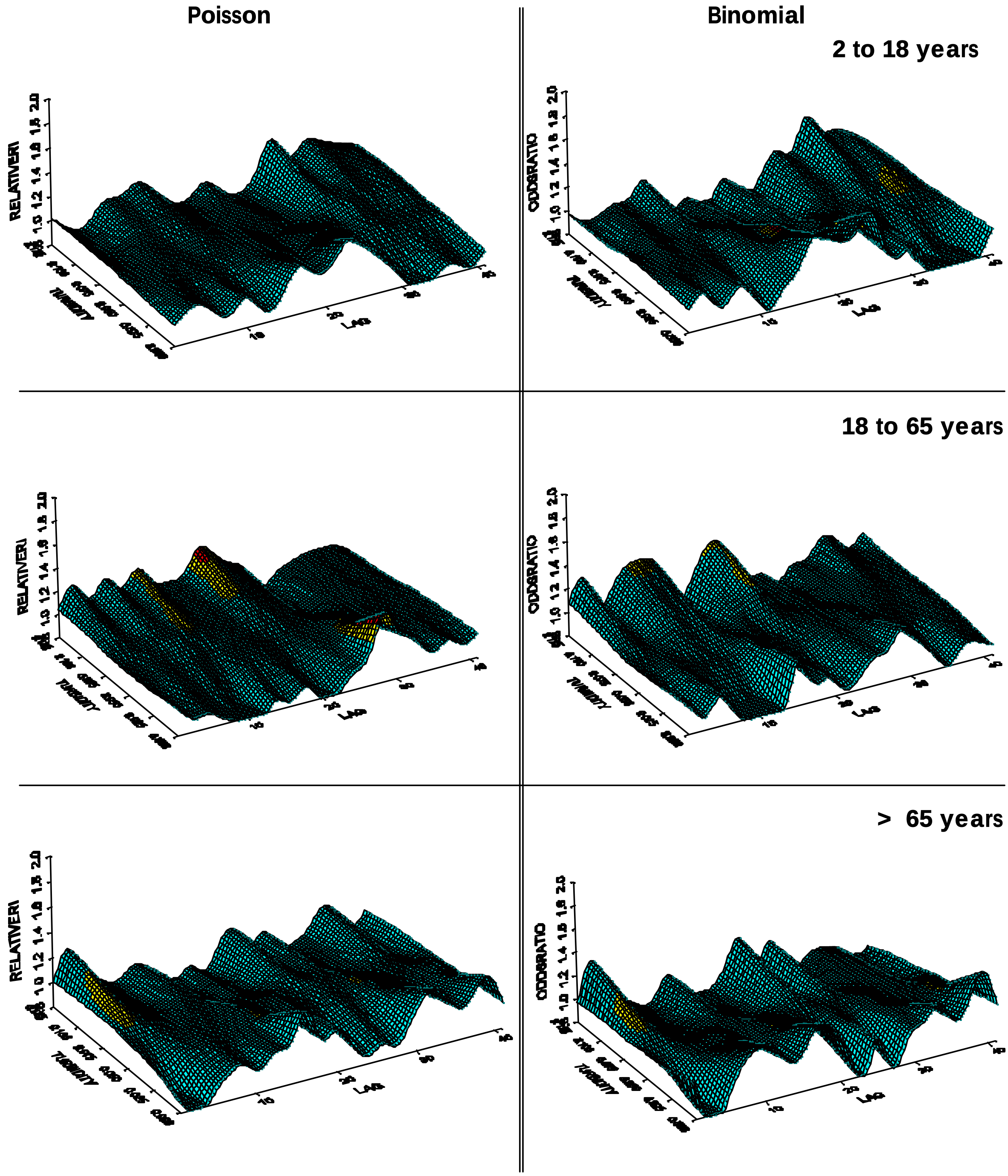
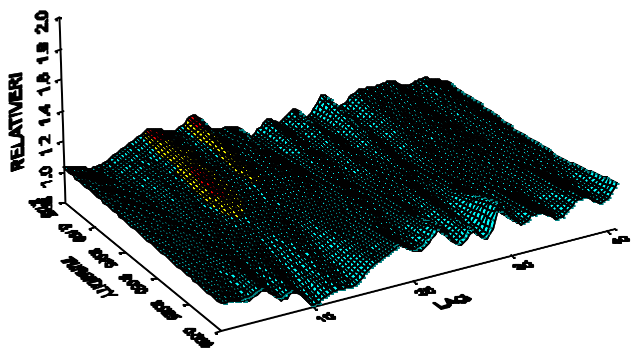
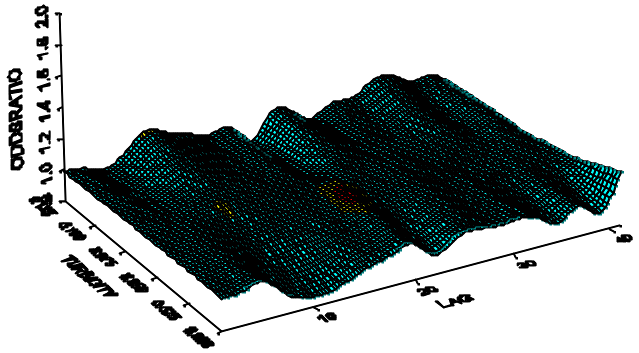


Figure 13b: 3-D time series surface plots of disease risk within the Rossdale water service area between February 10, 1993 to December 10, 1997: Emergency room billing data source

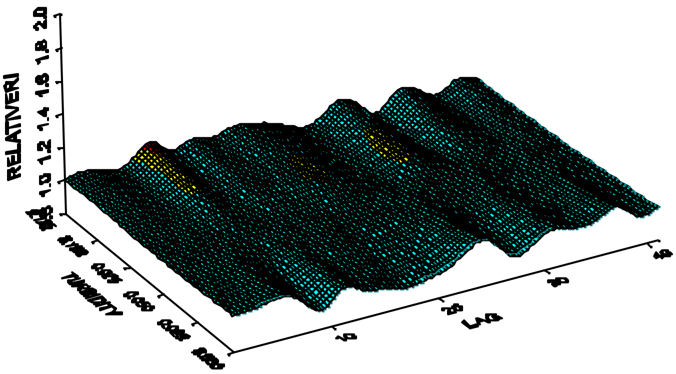
Poisson | **Binomial**

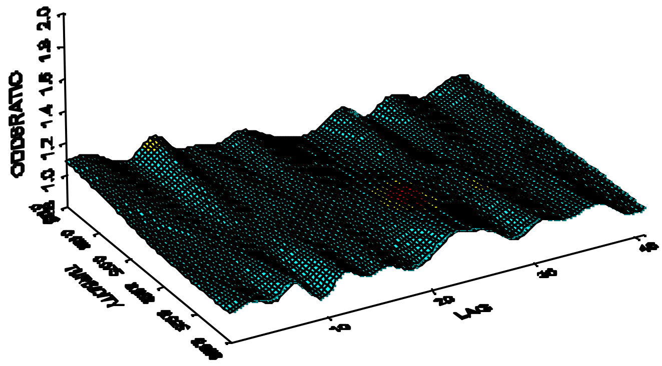
2 to 18 years



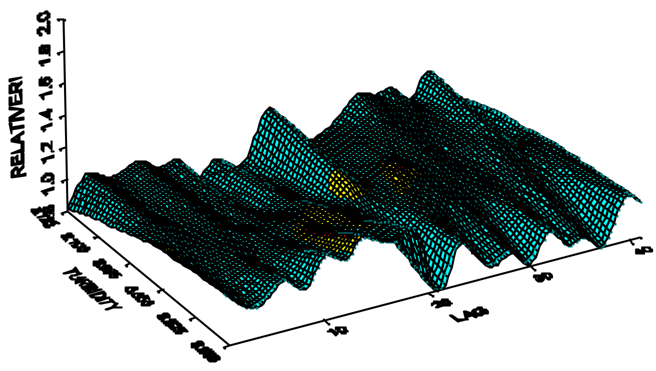


18 to 65 years





> 65 years



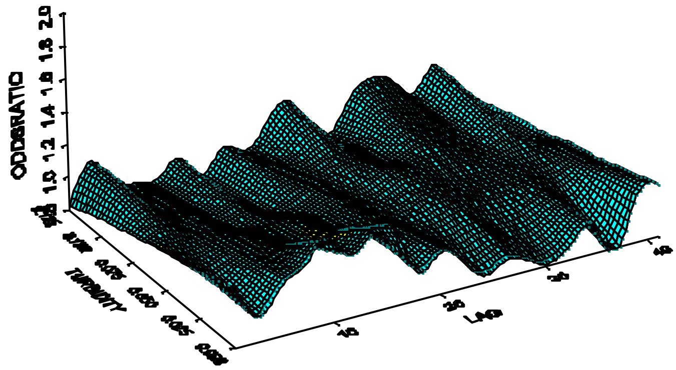
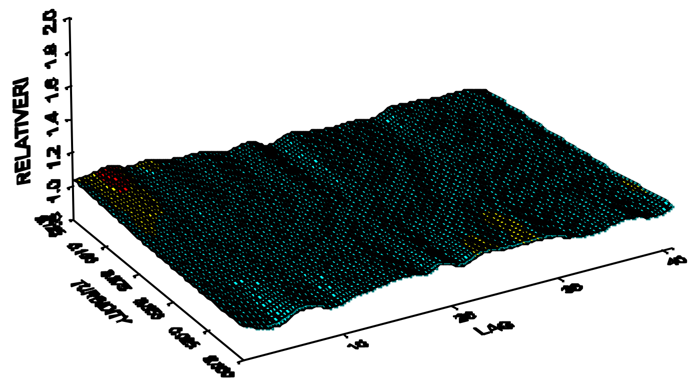


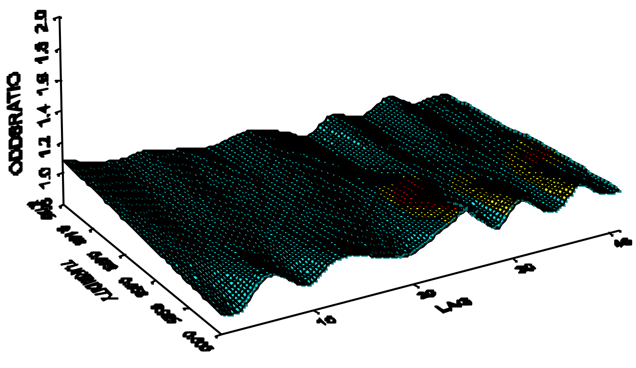
Figure 13c: 3-D time series surface plots of disease risk within the Rossdale water service area between February 10, 1993 to December 10, 1997: Physician-office billing data source

Poisson

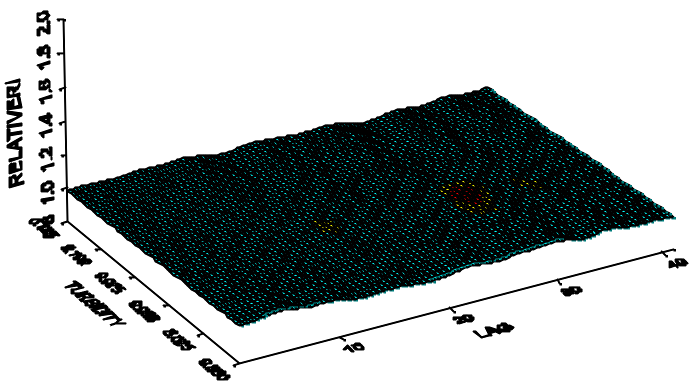
Binomial
(randomised subset)

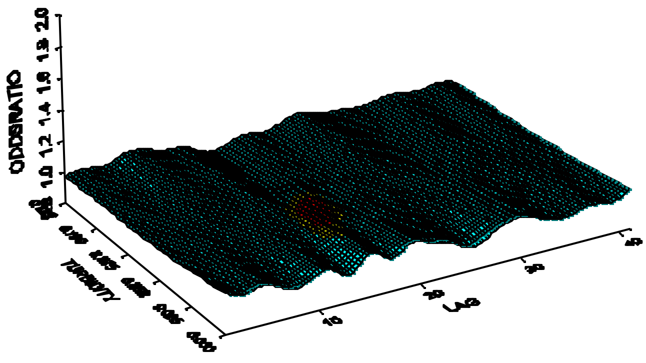
2 to 18 years



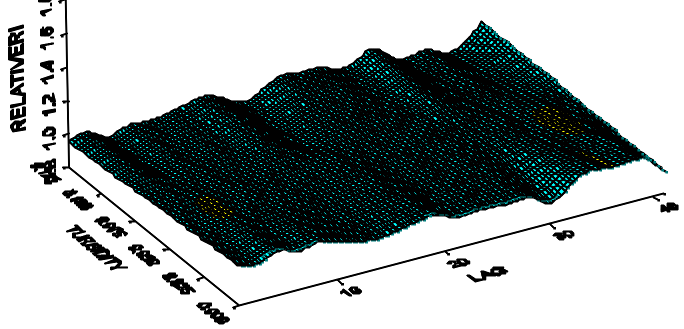


18 to 65 years





> 65 years



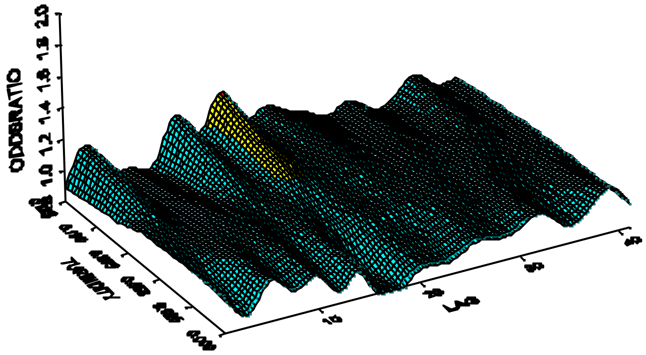
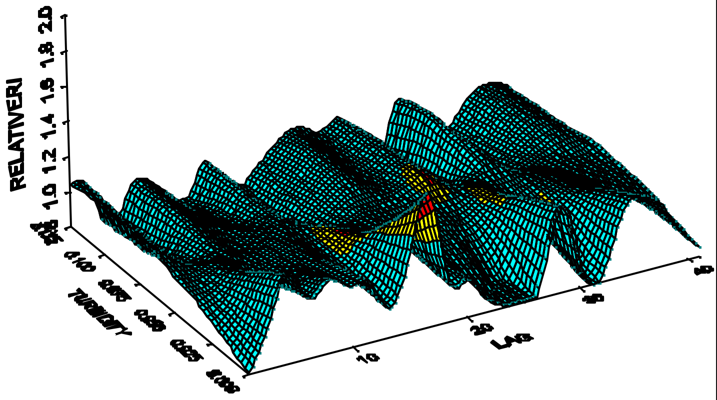
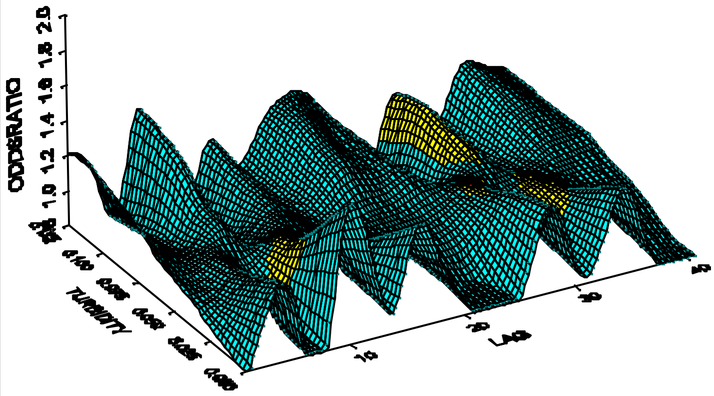


Figure 13d: 3-D time series surface plots of disease risk within the Rossdale water service area between February 10, 1993 to December 10, 1997: Long-term care billing data source

Poisson	Binomial

> 65 years





SECTION 5: DISCUSSION AND CONCLUSIONS

5.1 Introduction

Waterborne outbreaks of gastrointestinal illness are well documented in North America. In Milwaukee, U.S.A. in 1993, an estimated 403,000 people were infected with *Cryptosporidium* through a contaminated water supply (MacKenzie et al., 1994). In Canada, between 1986 -1993, approximately 150 suspected infectious drinking water outbreaks were reported to Health Canada (Todd, 1991, 1994, 1996, 1997, 1998). In Walkerton, Ontario in May of 2000, seven deaths and approximately 2000 illnesses resulted from the contamination of municipal well water with *E. coli* O157:H7 and *Campylobacter spp*. (Grey Bruce Health Unit, 2000). In The Battlefords, Saskatchewan, approximately 6000 persons developed gastroenteritis associated with waterborne cryptosporidiosis in April of 2001 (Stirling et al, 2001). These past outbreaks, together with recent studies that suggest that drinking water may be a substantial contributor to endemic (non-outbreak related) gastroenteritis (Payment et al., 1997; Schwartz et al., 1997; Isaac-Renton et al., 1999), demonstrate the vulnerability of many North American cities to waterborne diseases and have fuelled ongoing debates in Canada and the United States concerning the need for stricter water quality guidelines, changes in watershed management policies, and the need for additional water treatment.

EPCOR Water Services Inc. (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. Edmonton and the surrounding regions are serviced by two water treatment plants located within the city (Figures 1 and 2): the Rossdale plant and the E.L. Smith plant. The E.L. Smith treatment plant was built in 1976, while the Rossdale plant was built in the 1940's. The Rossdale plant has been upgraded several times since it was first constructed. Of particular interest for this study, on December 10, 1997 the Rossdale raw water intake site was moved towards the centre of the river in an attempt to improve raw water quality. At the same time, the introduction of particle counters at the Rossdale plant allowed for much better optimisation of the filters to minimise the effect of filter-to-waste periods, filter spikes, and particle increases at the end of the filter runs. Downstream of the E.L. Smith plant and upstream of the Rossdale plant, there are 85 storm sewers that discharge into the North Saskatchewan. Both plants draw raw water from the North Saskatchewan River and use clarification, softening, recarbonation, filtration, and disinfection in the water treatment process.

The North Saskatchewan River originates at the foot of the Columbia Ice-fields in the Rocky Mountains south-west of Edmonton, and flows directly through Edmonton. En route, numerous rivers and creeks feed the river. In contrast to the watersheds that serve as Vancouver's water source, the North Saskatchewan River watershed is not protected. Covering 28,000 square kilometres, the watershed has many potential points of pathogen introduction: recreational sites, treated wastewater discharge from upstream communities, private septic systems, and agricultural operations.

The primary objective of this investigation was to determine if endemic gastroenteritis among Edmonton residents was influenced by the municipal water supply from January 1993 to December 1998. This was achieved by investigating the relationships between health outcomes associated with gastroenteritis (hospital admissions, emergency room visits, physician visits, and long-term care visits) and residential drinking water supply and finished water quality. The impact of the changes implemented at the Rossdale plant on December 10, 1997 was addressed in the investigation, together with the effects of environmental parameters such as precipitation. Another objective of this investigation was to compare and contrast the utility of various water quality indicators in identifying potential relationships with gastroenteritis. In addition to turbidity, particle counts in finished water were examined, together with raw water indicators such as turbidity and coliform counts.

5.2 Methodological Overview

Together with descriptive analyses, two main methodological approaches were used in this study. A detailed discussion of the methodological approaches and data sources used in this study are provided in Section 3 of this report.

5.2 a) Multivariate logistic regression

Multivariate logistic regression was used to determine if differences in risk for endemic gastroenteritis existed among the water service areas (Rossdale vs. E.L. Smith), before and after the changes implemented at the Rossdale plant on December 10, 1997 (movement of the intake, and the introduction of particle counters). In the first of two approaches (GLM), cases (individuals with gastroenteritis related diagnoses) and controls (individuals with respiratory disease related diagnoses) were assigned to a water service area based on their place of residence. Separate models were evaluated for each outcome data source (hospitalisation, emergency room visit, physician visit, and long-term care visits), for all individuals greater than 2 years old. Age was fit as a categorical variable. In addition to water source and age, other variables included in the model were average household income and season. Household income was used as an indicator of socio-economic status and was assigned to individuals based on their enumeration area. Season was fit using splines.

In the second approach, multivariate logistic spatial modeling using a generalised additive model (spatial GAM) was carried-out to provide a visual representation of the geographic differences in endemic gastroenteritis risk among Edmonton residents. The objective of this analysis was to assess the spatial trend in risk as it related to water service areas. Modeling proceeded as above (multivariate logistic regression), but instead of fitting a water source categorical variable, latitude and longitude was fit using a loess smoothing function, and a variable corresponding to when the improvements took place at the Rossdale plant (December 10 , 1997). Season was also fit using a loess smoothing function.

5.2 b) Time series analysis

Similar to the Vancouver study (Aramini et al., 2000), a time series approach was used to investigate the temporal relationship between water quality and gastroenteritis. Using a generalised additive model (GAM), the objective of this analysis was to investigate and quantify the temporal associations between endemic gastroenteritis as measured by hospitalisations, emergency room, physician visits, and long-term care visits, and water quality parameters (primarily finished water turbidity) from 1993 to 1999. The modeling approach controlled for other significant and potentially confounding variables such as seasonal and long-term effects, and used nonparametric regression smoothers to assess the turbidity-gastroenteritis relationship. Two different, though related modeling approaches were used in this study: a Poisson regression approach and a Binomial (case-control) regression approach. For the Poisson modeling approach, the relationships between the daily numbers of health outcomes as measured by hospital admissions, emergency care visits, physician visits and long-term care visits and water quality from 0 to 40 days prior to health outcome event was investigated. For the Binomial (case-control) modeling approach, the relationship between case status (gastrointestinal vs. respiratory conditions) and water quality from 0 to 40 days prior to a health outcome event was investigated for each health outcome group. Each health outcome data set and age group (2-18 yrs, >18-65 yrs, >65 yrs) was modeled independently.

5.3 Discussion of Results

5.3 a) Descriptive analyses

Detailed descriptive summaries of the outcome data sets (hospitalisations, emergency room visits, physician office visits, and long-term care visits) and of the risk factor data sets (finished and raw water parameters, precipitation, average household income, etc) are provided in Section 4.1.

As anticipated, 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. 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. 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, summary statistics appeared to be equivalent. 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 must be interpreted with caution as these data were only available for 1998. Despite small improvements in finished water turbidity for the Rossdale plant after December 10, 1997, finished water turbidity values throughout the study for both plants were well within the Canadian drinking water turbidity guidelines [7].

The differences in water quality parameters among the water supplies supported the efforts to investigate the influence of water source (E.L. Smith, Rossdale before December 10, 1997, Rossdale after December 10, 1997) on endemic gastroenteritis using multivariate logistic regression, and to limit the time series analysis to individuals presumably at the greatest risk of waterborne gastroenteritis (persons supplied by the Rossdale plant prior to Dec 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 later subset.

Also of interest was the prominent geographic disparity in average household income among Edmonton residents. As anticipated, household incomes were generally higher in the Southwest parts of the city and away from the city centre. As socio-economic factors are considered to be key determinants of health, the inclusion of this potential confounder in the multivariate logistic regression approach was supported.

[7] Guidelines for Canadian Drinking Water Quality: http://www.hc-gc.gc.ca/ehp/ehd/catalogue/bch_pubs/dwgsup_doc/dwgsup_doc.htm

5.3 b) Multivariate logistic regression

Multivariate logistic regression results are presented in detail in Section 4.2a.

After controlling for potential confounders (average household income, age, seasonal trends), results of the multivariate logistic model which fit a categorical variable for water source, suggest a small decrease in the risk of gastroenteritis among residents supplied with Rossdale water following the changes that were implemented on December 10, 1997. As many factors could potentially affect both the risks of gastroenteritis and respiratory diseases during the study period, comparisons between service areas were limited to within the same time frame (either before, or after December 10, 1997). For the same reason, interpretation of the results was based on the relative change in the relationship between Rossdale and E.L. Smith service areas following December 10, 1997, and not on the absolute value of the parameter estimates of the models. Analyses of the four health outcome data sets demonstrated a trend towards a decrease in the risk of gastroenteritis among Rossdale vs. E.L. Smith serviced residents after the improvements at the Rossdale plant.

The interpretation of the logistic regression results should be made with caution as the magnitudes of the effects were relatively small (odds ratios near one). Odds ratios between 0.5 and 2.0 are generally considered to be relatively susceptible to the influence of uncontrolled confounders. It is also important to note that the improvements at the Rossdale plant are only a potential cause of the associations observed. Results demonstrate a trend towards a decrease in the risk of gastroenteritis (in comparison to respiratory diseases) among Rossdale serviced residents after December 10, 1997 when compared to E.L. Smith serviced residents. 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. Factors (other than drinking water) that may have impacted on endemic gastroenteritis or respiratory diseases differentially across service areas could have potentially contributed to the observed relationship. The lack of an obvious spatial pattern in risk with respect to the service areas further underlies the tenuous nature of this causal hypothesis. Nevertheless, the associations observed are consistent with the improvements made at the Rossdale plant.

5.3 c) Time series analysis

Time series results are presented in detail in Section 4.2b.

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. Nevertheless, no significant lags were identified between daily finished water turbidity and gastroenteritis among Rossdale serviced residents, suggesting the absence of a significant association between finished water quality and endemic gastroenteritis. 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. Similar to the spatial analysis, the final model was adjusted for seasonal and temporal effects. 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 (daily mean turbidity, daily median turbidity, and daily maximum turbidity) from the Rossdale plant prior to December 10, 1997 and endemic gastroenteritis.

The criteria for identifying a significant lag were defined using both statistical and epidemiological principles. The sporadic statistically significant associations observed in the 3-D time series plots were subsequently assessed to acquire additional detail on the relationship between a specifically lagged turbidity measurement and gastroenteritis. The primary statistical criterion for identifying a significant lag was based on comparing the change in deviance in models with and without the lagged variable, using the likelihood-ratio test. This statistical comparison enabled the evaluation of the overall effect of the variable. However, by conducting multiple statistical tests for the 40 lags, the probability of erroneously detecting a statistically significant association was increased (Type I error). Therefore, only lags that were significant over two to three consecutive days were further evaluated for consistency among different age groups and data sources. Using the criteria outlined above (including consistency), no *significant* relationships were identified between lagged turbidity values and gastroenteritis.

The final models derived for the binomial and poisson models in the Edmonton time series analysis were similar to those found in the Vancouver study. However, compared to the results reported in the Vancouver time series study, the relationships (relative risks and odd ratios) between finished water turbidity and endemic gastroenteritis as assessed by hospital admissions, emergency room visits, and physician visits, were much smaller in magnitude in the Edmonton study. Furthermore, in the Edmonton study, only sporadic statistical associations were observed with turbidity, and consistency of the relationships was not maintained across the various health outcome data sources.

Finished water turbidity has been used as an indicator of water quality in other drinking water investigations (Schwartz et al, 2000; Morris et al, 1998; Schwartz et al, 1997). While other water quality parameters were available for analysis in this study, finished water turbidity was found to provide the best fit for the data, and provided the most stable model parameter estimates. It was this measured variable upon which temporal gastrointestinal relationships with water quality were determined. In contrast, the use of raw water quality indicators (turbidity and faecal coliform counts) and environmental parameters (precipitation and temperature) provided very unstable estimates, even after extensive smoothing of the data was carried out. The later observation demonstrates the lack of significant associations between the fluctuating raw water parameters and precipitation, and endemic gastroenteritis.

5.4 Conclusion

In comparison to the results of the Vancouver Time Series study, 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 relationship was identified between finished water quality 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.

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 (using multivariate logistic regression, GLM), 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, GAM), together with the lack of a significant temporal relationship between endemic gastroenteritis with finished water turbidity (using time series analysis, GAM), 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.

REFERENCES

Alberta Environment Protection. 1997. Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems. http://www3.gov.ab.ca/env/protenf/publications/StormDrainageDec97.pdf

Aramini, J., Wilson, J., Allen, B., Holt, J., Sears, W., McLean, M., Copes, R. 2000. Drinking water quality and health care utilization for gastrointestinal illness in Greater Vancouver. Health Canada.

Brillinger, D.R. 1994. Examples of scientific problems and data analyses in demography, neurophysiology, and seismology. J. Comp. Graph. Stat 3:1-22

Chambers, J.M., Hastie, T.J. (eds). 1992. Statistical models in S. Wadsworth & Brooks, Pacific Grove, CA.

Cleveland, W.S., and Devlin, S.J., (1988) Locally-weighted Regression: An Approach to Regression Analysis by Local Fitting. J. Am. Statist. Assoc., Vol. 83, pp 596-610.

Cook, D.G., Pocock, S.J. 1983. Mutiple regression in geographical mortality studies, with allowance for spatially correlated errors. Biometrics 39:361-371.

Curriero, F.C., Patz, J.A., Rose, J.B., Lele, S. 2001. The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. Am. J. Pub. Health, 91:1194-1199.

Fahrmeir, L., Tutz, G. 1994. Multivariate statistical modeling based on generalized linear models. Springer-Verlag, New York. p. 45

Grey Bruce Health Unit. 2000. The Investigative Report Of The Walkerton Outbreak Of Waterborne Gastroenteritis. http://www.publichealthgreybruce.on.ca/_private/Report/SPReport.htm

Hastie, T.J., Tibshirani, R.J. 1990. Generalized additive models. Chapman and Hall, London, p. 335.

Health Canada. 1996. Guidelines for Canadian drinking water quality - sixth edition. Canada: Supply and Services Canada.

Isaac-Renton, J., J. Blatherwick, W.R. Bowie, et al. 1999. Epidemic and endemic seroprevalence of antibodies to Cryptosporidium and Giardia in residents of three communities with different drinking water supplies. American Journal of Tropical Medicine and Hygiene; 60:578-583.

MacKenzie, W.R., Hoxie, N.J., Proctor, M.E., Gradus, M.S., Blair, K.A., Peterson, D.E., Mazmierczak, J.J., Addiss, D.G., Fox, K.R., Rose, J.B., Davis, J.P. 1994. A massive outbreak in Milwaukee of *Cryptosporidium* infection transmitted through the public water supply. N. Engl. J. Med., 331:161-167.

McCullagh, P., Nelder, J.A. 1983. Generalized Linear Models. Chapman and Hall, London, UK.

Morris, R.D., Naumova, E.N., Griffiths, J.K. 1998. Did Milwaukee experience waterborne cryptosporidiosis before the large documented outbreak in 1993? J. Epidemiol., 9:264-270.

Payment, P., J. Siemiatychi, L.Richardson, et al. 1997. A prospective epidemiologic study of gastrointestinal health effects due to the consumption of drinking water. International Journal of Environmental Health Research, 7: 5-31.

Preisler, H.K., Rappaport, N.G., Wood, D.L. 1997. Forest Science. 43(1) 71-77. Regression methods for spatially correlated data: An examle using beetle attacks in a seed orchard.

Schwartz, J, Levin, R., Goldstein, R. 2000. Drinking water turbidity and gastrointestinal illness in the elderly of Philadelphia. J. Epidemiol. Community Health, 54:45-51.

Schwartz, J., Levin, R., Hodge, K. 1997. Drinking water turbidity and pediatric hospital use for gastrointestinal illness in Philadelphia. J. Epidemiol., 8:615-620.

Sakamoto, Y., Ishiguro, M., and Kitagawa G. 1986. Akaike Information Criterion Statistics. D. Reidel Publishing Company.

Steel, R.G.D., Torrie, J.H., Dickey, D.A. 1997. Principles and procedures of statistics: A biometrical approach, 3rd edition. McGraw-Hill, Boston. p. 90.

Stirling, R., Aramini, J., Ellis, A., Lim, G., Meyers, R., Fleury, M., Werker, D. North Battleford, Saskatchewan, Spring 2001: Waterborne cryptosporidiosis outbreak. Health Canada. http://www.health.gov.sk.ca/info_center_pub_health_can_epi_report_NB.pdf

Todd, E.C.D. 1991. Foodborne and waterborne disease in Canada: 1985-86. Polyscience Publications, p. 205.

Todd, E.C.D. 1994. Foodborne and waterborne disease in Canada: 1987. Polyscience Publications, p. 196.

Todd, E.C.D. 1996. Foodborne and waterborne disease in Canada: 1988-89. Polyscience Publications, p. 318.

Todd, E.C.D. 1997. Foodborne and waterborne disease in Canada: 1990-91. Polyscience Publications, p. 286.

Todd, E.C.D. 1998. Foodborne and waterborne disease in Canada: 1992-93. Polyscience Publications, p. 301.