THE INVESTIGATIVE REPORT OF THE WALKERTON OUTBREAK OF WATERBORNE GASTROENTERITIS

MAY – JUNE, 2000

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Prepared by the Bruce-Grey-Owen Sound Health Unit
EXECUTIVE SUMMARY

This report describes the findings of investigations led by the Bruce-Grey-Owen Sound Health Unit (BGOSHU) with the assistance of Health Canada and the Ontario Ministry of Health and Long-Term Care into an outbreak of gastroenteritis in Walkerton, Ontario, May and June, 2000. The purpose of these investigations was to determine the scope, the likely cause and the contributing factors of the outbreak. This incident represents the first documented outbreak of *Escherichia coli* O157:H7 infection associated with a municipal water supply in Canada and the largest multi-bacterial waterborne outbreak in Canada to date.

Identification of the Walkerton outbreak was initiated by the early recognition of pediatric cases from Walkerton of bloody diarrhea and severe abdominal cramps reported to the BGOSHU on May 19, 2000. After inquiries by the Health Unit revealed an increase in diarrheal illness in long-term care facilities, elementary schools and emergency departments in the Walkerton area, an outbreak investigation was launched. While most of the ill were residents of Walkerton, a number of individuals lived in outlying communities. Two days of exhaustive investigation failed to identify any common food exposure or community event that could account for the cases. Since residing in, or visiting Walkerton was the only common factor between those ill, the municipal water supply appeared to be the plausible vehicle for the outbreak.

A stool culture taken from one of the initial cases was reported on Saturday, May 20 to be presumptive positive for sorbitol negative *E. coli* (a marker for *E. coli* O157:H7), and a preliminary report early on May 21, identified the stool culture isolate as *E. coli* O157. Despite reassurances from the Walkerton Public Utilities Commission (PUC) that the water was safe and secure, a Boil Water Advisory was issued to the town of Walkerton by the Health Unit at 1:30 p.m. May 21. Subsequent testing of the municipal water distribution system confirmed contamination with *E. coli* and coliform bacteria.

On May 22, the BGOSHU made a request to the Ontario Ministry of Health and Long-Term Care (OMHLTC) for a federal field epidemiologist to assist. Due to the nature and scope of the outbreak, a team of epidemiologists from Health Canada was assembled and dispatched to Owen Sound. The OMHLTC also provided an epidemiologist to collaborate in the investigation.

The epidemiological investigation included both a descriptive study and a cross-sectional study. Intensive case-finding for the descriptive study ultimately led to the identification of 1346 reported cases of gastroenteritis with exposure to Walkerton municipal water. Among these, 799 were residents of the town of Walkerton. Based on estimates derived from the cross-sectional study, the number of Walkerton residents that became ill was approximately 1286. The overall estimated number of cases associated with the outbreak was over 2300 people.
Of the 1346 reported cases, 1304 were considered to be primary (exposed to Walkerton municipal water), 39 were secondary (exposed to a primary case and not to Walkerton municipal water) and 3 were unclassified. In total, stool samples from 174 people had presumptive laboratory evidence of *E. coli* O157; 167 of which were confirmed as *E. coli* O157:H7. Stool samples from 116 people were confirmed with *Campylobacter* species (spp.). Sixty-five patients were admitted to hospital and of these 27 developed hemolytic uremic syndrome (HUS). Six people died as a result of the outbreak. The median age of reported cases was 29 years (range <1 to 97 years), 57% were female. While 92% of the ill individuals resided in Bruce and Grey Counties, 8% resided in other parts of the province, and two individuals lived in other provinces.

The onset for illness of the majority of cases occurred after May 12, and continued until late June, with a peak in illnesses between May 17 and 19. Within five days of issuing the boil water advisory, the number of new cases dropped substantially. Several cases were identified with onset of illness as early as April 15. This included some individuals infected with the same strain of *E. coli* O157:H7 as the majority of the outbreak cases, according to genetic finger-printing. Based on these early cases and several positive total coliform samples in the water in April, it is possible that low numbers of bacteria were entering the Walkerton municipal water distribution system in April and early May. It is hypothesized, however, that heavy rainfall in mid-May was responsible for gross contamination of the distribution system resulting in the majority of the illnesses. Mapping of the cases in Walkerton by location of residence confirmed the widespread nature of the illnesses and supported the hypothesis that municipal water was the cause of the outbreak.

Analysis of the cross-sectional study of Walkerton households conducted in June, confirmed that people residing in homes connected to the municipal water supply and consuming Walkerton water were 11.7 times more likely to develop gastroenteritis than those not exposed to Walkerton water. A dose response relationship was demonstrated in that the risk of illness increased with the quantity of water consumed. This study also found that despite the boil water notice and extensive publicity, a small portion of the residents in Walkerton continued to expose themselves to the water through various routes, including brushing teeth with the water and occasionally drinking it.

Examination of well records from the PUC indicated that Wells 5 and 6 were supplying the town during the critical exposure time prior to onset of illnesses. Testing of water samples from the distribution system on May 21 and of water from Well 5 on May 23 demonstrated significant contamination with coliform and *E. coli* bacteria. Subsequent DNA analysis of these samples by polymerase chain reaction (PCR) confirmed the presence of the O157, H7 and verotoxin genes, supporting the likelihood that *E. coli* O157:H7 had been present in these samples. Test results of Wells 6 and 7 on May 23 were negative for coliforms, including *E. coli* bacteria. Historic well reports and the August 18, 2000 interim report by Golder Associates
confirmed that Well 5 is subject to surface water contamination and elevated turbidity.

Environmental testing of 13 livestock farms within a four kilometer radius of the three wells, identified human bacterial pathogens in animal manure on all, but 2 farms. On nine farms, *Campylobacter* spp. were identified and, on two farms, both *E. coli* O157:H7 and *Campylobacter* spp. were found; this included a farm adjacent to Well 5. The molecular subtyping and phage-typing of the *E. coli* O157:H7 and the *Campylobacter* spp. isolates from this farm were identical to those found in the majority of the human cases. While investigators could not prove the pathogens were present prior to the outbreak, the evidence suggested the pathogens that entered Well 5 likely originated from cattle manure on this farm. A simulation model of rainfall and the drainage pattern in the vicinity of Well 5 indicated that rain falling on the barnyard and adjacent fields would have drained toward Well 5.

A series of unfortunate circumstances occurred to cause an outbreak of this magnitude. These included heavy rains accompanied by flooding, *E. coli* O157:H7 and *Campylobacter* spp. present in the environment, a well subject to surface water contamination and a water treatment system that may have been overwhelmed by increased turbidity. This situation emphasizes the importance of secure water sources and adequate water treatment in ensuring a safe water supply to a community. Bacterial monitoring can only identify a contaminated source after the contamination has spread through the water system and put the public at risk.

The Walkerton outbreak calls into question the safety of groundwater sources that may be under the influence by surface water especially under flood conditions. Historically, groundwater sources have been assumed to be secure and treated with chlorination only. However, in light of this tragedy, this approach needs to be re-evaluated. Such an evaluation should take into account all current and future pressures on land use including human population density and agricultural activities.
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Health Canada

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THE INVESTIGATIVE REPORT OF THE WALKERTON OUTBREAK OF WATERBORNE GASTROENTERITIS MAY-JUNE 2000

1.0 INTRODUCTION

On May 19, 2000, an outbreak of gastroenteritis, including bloody diarrhea, in the Walkerton area was identified by the Bruce-Grey-Owen Sound Health Unit (BGOSHU). This outbreak, caused by *Escherichia coli* O157:H7 and *Campylobacter* species (spp.), resulted in an estimated 2000 cases and six deaths linked to contamination of the municipal water supply for the Town of Walkerton.

Walkerton is a community of approximately 5000 people within the newly formed municipality of Brockton in Bruce County. The town is located in one of Ontario’s prime agricultural areas, 180 kilometres north west of the City of Toronto. At the time of the outbreak, the town’s drinking water was a groundwater supply obtained from three drilled wells each with chlorination units (Figure 1).
This report describes the findings of an investigation into the cause and scope of the outbreak led by the BGOSHU, Health Canada and the Ontario Ministry of Long-Term Care (OMHLTC).
2.0 BACKGROUND

In Canada, between 1990 and 1998, 1100 to 1600 cases of verocytotoxigenic *E. coli* infection were reported annually, 400 to 600 of these were in Ontario. The majority of these cases were due to *E. coli* O157:H7 infection. Between 1986 and 1998, 9800 to 14000 cases of *Campylobacter* spp. infection were reported annually nation-wide; 5000 to 7500 cases were reported by the province of Ontario. According to the Ontario Reportable Diseases Information System (RDIS), which tracks reported cases of notifiable diseases in the province, for the period from 1989 to 1999, Bruce and Grey Counties identified an average of 13 cases of *E. coli* O157:H7 infection and 84 cases of *Campylobacter* spp. infection per year. Of these, only one to two cases of infection with *E. coli* O157:H7 and two to three cases of infection with *Campylobacter* spp. occurred in Walkerton annually. These organisms are transmitted through the fecal-oral route and infection can result from consumption of contaminated food or water, or as a result of direct contact with infected animals or people. The expected time between exposure and onset of illness, defined as the incubation period, for *E. coli* O157:H7 infection is a median of three to four days (range three to eight days). For *Campylobacter* spp. infection the incubation period has a median of two to five days with a range of one to ten days depending on the dose ingested.

Drinking water-related outbreaks of pathogenic *E. coli* have been reported as early as 1965 in Sweden, and 1971 in the United States \(^1\). The earliest documented drinking water-related outbreak of *Campylobacter* spp. occurred in Vermont in 1978 \(^2\), in a municipal system in which the water was inadequately chlorinated.

Two drinking water-related outbreaks involving both *E. coli* O157:H7 and *Campylobacter* spp. have been reported to date. The first occurred in Fife, Scotland, in March 1995 \(^3\). The second outbreak occurred at the Washington County Fair, in New York State, in August 1999 \(^4,5\). A detailed summary of key literature relevant to this outbreak is provided in Appendix A.
3.0 OUTBREAK RECOGNITION AND INITIAL RESPONSE

The following is a detailed account of the first five days of the investigation conducted by the BGOSHU.

3.1 FRIDAY, MAY 19, 2000

The BGOSHU was contacted by a Walkerton retirement home with reports of three residents experiencing diarrhea and vomiting. Standard outbreak procedures were being applied at the retirement home. The Health Unit also received a call from an Owen Sound physician who reported that two elementary school children with bloody diarrhea had been referred to her from the South Bruce Grey Health Centre – Walkerton Site (henceforth, the Walkerton Hospital). Both children were admitted to Grey Bruce Health Services – Owen Sound (henceforth, the Owen Sound Hospital). Stool samples were taken and their families were interviewed to try to determine a common food source to explain the infection. None was found.

Two elementary schools in Walkerton were subsequently contacted by the BGOSHU. Both schools reported an increase in absenteeism beginning on May 17, with the junior grades most affected. In addition, the Walkerton Hospital was called to determine if any patients had been seen with enteric symptoms. They reported that of the eight patients seen that day, seven were children and seven of the eight had a three-day history of diarrhea, cramping, and the development of bloody diarrhea. At that time, no stool samples had been collected from these patients.

The BGOSHU then received a report of an enteric outbreak involving six patients at the home for the aged in Walkerton. The date of onset for diarrhea was May 18. Standard outbreak procedures were in place. The reporting staff member inquired about the validity of a local rumour concerning contamination of the municipal water supply. The Health Unit contacted the Walkerton Public Utilities Commission (PUC) and was assured the municipal water supply was secure. Despite this information, the home for the aged decided to boil all drinking water in their facility.

The BGOSHU advised the Walkerton Hospital emergency department to collect stool specimens, withhold anti-motility drugs, and administer supportive therapy until an organism was isolated by the laboratory. The hospital was also forewarned about possible admissions from the local retirement home and home for the aged that were experiencing outbreaks.

The Owen Sound Hospital laboratory informed the BGOSHU that presumptive results would be ready by the afternoon of May 20. The Owen Sound Hospital laboratory was asked to notify the BGOSHU if samples tested positive for any enteric pathogen.

Late in the afternoon, the BGOSHU investigators in the Owen Sound office contacted the Walkerton area public health inspector to determine if there had been any recent...
community events that might suggest a common source of exposure. He did not know of any such event.

3.2 SATURDAY, MAY 20

In the morning, the Owen Sound Hospital laboratory notified the BGOSHU of a presumptive *E. coli* O157 from a stool specimen of one of the patients admitted the day before. A second patient was reported as having “normal fecal flora”.

The BGOSHU contacted the three hospitals located in Walkerton, Hanover and Owen Sound. All were collecting stool samples and fielding calls from ill residents in Walkerton and surrounding communities. All hospitals were alerted to the Health Unit’s concern of possible *E. coli* O157:H7 infection and the risk of subsequent hemolytic uremic syndrome (HUS) in children under five years of age and in the elderly.

Twenty patients with enteric symptoms had already been seen in the Walkerton Hospital. One child and one adult had been admitted due to dehydration. The Owen Sound Hospital reported one case of bloody diarrhea. The Hanover and District Hospital (henceforce the Hanover hospital) had seen one patient with bloody diarrhea who was a sibling of a patient in the Owen Sound Hospital.

The BGOSHU contacted the Walkerton PUC again and inquired as to the safety of the Walkerton water supply. The PUC was informed of concerns that were being expressed by residents who visited the Walkerton Hospital regarding the quality of the Walkerton water. The Health Unit was assured by the PUC that the water was safe and secure. The BGOSHU recommended the PUC issue a press release to reassure the community of the security of the water system. Based on the PUC information, the BGOSHU continued to investigate for other potential sources of the outbreak.

3.3 SUNDAY MAY 21

Approximately forty patients had been seen during the previous evening and early morning in the three area hospitals. About 100 telephone calls had been documented from individuals concerned about diarrhea, bloody diarrhea, fever, and severe stomach cramping. The Owen Sound Hospital had admitted two more children, aged two and 16 years. Despite the fact that the youngest patient was from Hanover, it was determined that the child had recently been in Walkerton and consumed food and water. This finding reinforced the hypothesis that living in or visiting Walkerton was a common risk factor among the cases.

The BGOSHU was advised by the Owen Sound Hospital laboratory that the stool specimen of the index patient admitted May 18 was positive for *E. coli* O157 and another specimen was presumptive positive. The Health Unit considered this to be sufficient microbiological evidence to establish this outbreak was due to *E. coli* O157.
An outbreak number was assigned and provided to the Walkerton Hospital, all peripheral hospitals, and laboratories. The BGOSHU advised the Huron County Health Unit and Wellington-Dufferin-Guelph Health Unit of their activities.

All investigations thus far had failed to identify any plausible source for the infection other than the Walkerton municipal water supply. Therefore, despite the information provided by the PUC, the BGOSHU issued a Boil Water Advisory at 1:30 p.m. Information regarding the Boil Water Advisory was given to the two local radio stations (AM and FM) in Owen Sound and Wingham. Telephone calls were made to the Walkerton PUC, the Chief Medical Officer of Health for Ontario, the mayor of Brockton, the BGOSHU Board of Health Chair, the local Ontario Ministry of the Environment (MOE) office, local hospitals and the local Boards of Education about the advisory.

A team of BGOSHU staff met at the Health Unit at 2:00 p.m. Advice was given to local physicians not to use antibiotics in treating suspected outbreak cases and to monitor patients under the age of five for impending renal failure.

To assist in the follow-up of ill patients, the BGOSHU created line-listing forms, which were faxed to the Owen Sound, Walkerton, and Hanover Hospitals. Hospitals were asked to complete the form and fax this information back to the Health Unit each day.

The local Medical Officer of Health contacted the OMHLTC to request staffing assistance for the Walkerton Hospital.

The London Regional Public Health Laboratory was contacted and arrangements were made for the submission of Walkerton water samples. Twenty-one water samples from the distribution system were taken from sites throughout Walkerton and those samples were driven to London (arrived in London at 12:45 a.m. Monday morning). Arrangements were made to collect and send an additional 21 Walkerton water samples on Monday.

**3.4 MONDAY MAY 22**

Line listings of all cases seen in the area hospitals were sent to the Health Unit. Staff began telephoning the 120 identified to inquire about the onset of symptoms, their place of residence and possible exposures. The Medical Officer of Health phoned parents of the identified children under the age of five to warn them of renal failure symptoms and to seek follow-up testing. The Health Unit became aware of at least one child, who had been transferred to the London Children’s Hospital and was critically ill.

The MOE was contacted and requested to investigate the operation and security of the Walkerton water system.
By the end of the afternoon, a graph of the number of cases identified by the date of their onset of symptoms was prepared which clearly indicated a point source of infection. Addresses of those affected were also plotted on a map of Walkerton, which indicated that the distribution of cases was throughout the community.

Information about the Boil Water Advisory and outbreak investigation activities at the Owen Sound office were sent to the BGOSHU branch offices and a voice mailbox was set up for people calling about the outbreak.

The local Medical Officer of Health contacted The Chief Medical Officer of Health to request the assistance of a field epidemiologist from Health Canada for the investigation. The Associate Director of the Field Epidemiology Training Program was contacted by the OMHLTC regarding the BGOSHU request. A field epidemiologist was identified who could be dispatched the following day.

3.5 TUESDAY MAY 23

At 8:45 a.m., the London Regional Public Health laboratory phoned the BGOSHU to report that two of the Walkerton water samples taken by the Health Unit on Sunday showed the presence of coliform and *E. coli* bacteria. In addition, the samples taken Monday were presumptive positive for the same bacteria, indicating that the water was contaminated. The Walkerton PUC, the mayor of Brockton, and the MOE were immediately contacted regarding these water results.

At 11:00 a.m., the Walkerton Hospital hosted a joint Health Unit and Hospital media conference. The primary purpose of the media conference was to inform the public about the outbreak, potential complications of the infection by *E. coli* O157:H7 and to take the necessary precautions. At 1:00 p.m., a meeting with the local physicians was hosted by the hospital to warn doctors of the complications of *E. coli* O157:H7, treatment options, and testing to determine those children at risk of renal failure. At 2:00 p.m., BGOSHU staff met with Brockton council to brief them on the findings.
3.6 BGOSHU OUTBREAK MANAGEMENT

Following the recognition of the outbreak, the BGOSHU implemented an outbreak control team. The team was composed of staff of the BGOSHU, epidemiologists from Health Canada and the OMHLTC, and other provincial Health Unit staff who provided assistance. The outbreak control team reviewed all information regarding the outbreak and developed priorities for outbreak control, public education and investigation and analysis. Key activities included:

- Regular Outbreak Control team meetings
- Regular media conferences
- Arrangements for staff from other local Health Units to assist the BGOSHU.
- Stationing Health Unit staff at the Walkerton Hospital, in the Emergency Department
- Using the Health Unit Internet web site to efficiently disseminate information to the community and the media.
- Liaising with the Brockton Response Centre
- Liaising with the Boards of Education, long-term care facilities, day care and other institutions.
- Sampling of Walkerton water and inspection of food premises in Walkerton.
- Weekly meetings with the Ministry of the Environment, the Ontario Clean Water Agency, the Municipality of Brockton, and various consulting firms contracted by the Municipality and PUC.
- Assembling an expert advisory panel to assist in the determination of water risks and the process required for lifting the Boil Water Advisory.
- Participation in public meetings in the town of Walkerton to provide information on public health issues to residents.
- Development of a descriptive study, a cross-sectional study, and an environmental investigation of areas surrounding the town wells including farms.
4.0 LABORATORY METHODS

Bacterial enteric illnesses were confirmed by culture of stool specimens, however, not everyone who was ill necessarily sought medical attention or provided these types of specimens. Laboratory isolation of pathogens from human specimens was generally performed by hospital or private laboratories. Further characterization of the human isolates and those derived from environmental samples was conducted at the Central Public Health Laboratory (CPHL), Toronto, Ontario and the National Laboratory for Enteric Pathogens (NLEP), Winnipeg, Manitoba.

4.1 CENTRAL PUBLIC HEALTH LABORATORY

Stool specimens submitted from patients (both symptomatic and asymptomatic) in Cary-Blair transport medium were screened for bacterial enteric pathogens, including E. coli O157:H7, Campylobacter, Salmonella, Shigella, Yersinia, and Aeromonas using standard laboratory procedures.

Bovine rectal swabs and manure collected from various farm sites were also screened for enteric pathogens.

Well water samples and surface waters from sites in the Walkerton area were tested for coliforms and E. coli using the presence-absence method and the membrane filtration technique. Detection of Campylobacter spp. and E. coli O157: H7 in water was accomplished using a liquid enrichment technique. Immunomagnetic Separation (Dynal, Lake Success, NY) was used to enhance detection of E. coli O157: H7 from environmental samples. Presumptive E. coli O157 isolates were confirmed serologically for O157 and H7 antigens, using standard slide agglutination and tube agglutination techniques with in-house prepared anti-sera, respectively. Verotoxin production was detected using the ProspecT STEC Microplate Assay (Alexon-Trend, Ramsey, MN). All E. coli O157:H7 isolates were further typed using pulsed-field gel electrophoresis (PFGE), according to the Center for Disease Control protocol.

Detection of the H7, O157 and verotoxin genes were performed on selected environmental and clinical specimens using polymerase chain reaction (PCR) nucleic acid amplification methods according to referenced protocols.

E. coli O157:H7 and Campylobacter spp. isolates were also submitted to the NLEP for phagetyping, verotoxin typing, and serological and molecular (Campylobacter spp.) subtyping.

All presumptive and confirmed results were telephoned and or faxed to the Public Health Branch, the OMHLTC team member and the BGOSHU.
4.2 NATIONAL LABORATORY FOR ENTERIC PATHOGENS

*E. coli* O157:H7 isolates were phage-typed using standard techniques described previously \(^{12,13}\). Verotoxin detection was determined by tissue culture method as previously described \(^{14,15}\) and subtyping of verotoxin genes was done by PCR according to the method of Meng et al \(^{16}\) and Tyler et al \(^{17}\).

*Campylobacter* spp. isolates were serotyped according to the Lior scheme \(^{18}\) and the Penner scheme \(^{19}\). Phage typing of *Campylobacter* spp. isolates was performed as described by J. A. Frost \(^{20}\). These phages were propagated by modified soft agar overlay technique \(^{21}\). Phage reactions were examined against dark background using 10x hand lens and recorded as degrees of lysis using standard nomenclature \(^{20}\).

A detailed description of all laboratory methods is provided in Appendix B.
5.0 DESCRIPTIVE STUDY

A number of investigations were carried out to define and describe the population affected, the time frame, and the geographic distribution of the outbreak. These investigations included three components:

- Case ascertainment
- Spatial distribution of cases
- Physician survey

5.1 CASE ASCERTAINMENT

5.1.1 Methods

During the weekend of May 20, 2000, the BGOSHU began active case finding using emergency room and admission patient logs from three local hospitals. To assist in the follow up of ill patients, the BGOSHU created a line listing form (Appendix C) which was provided to the Owen Sound, Walkerton and Hanover hospitals. The criterion for inclusion onto the emergency room line listing were anyone who visited the hospital with diarrhea, bloody diarrhea, cramping, vomiting or fever.

In addition to individuals identified through hospital reports, people who contacted the BGOSHU directly, or who were identified by the laboratory as presumptive positive for *E. coli* O157 or *Campylobacter* spp. were added to the line listing form. To further identify cases, the OMHLTC advised all Ontario Health Units on May 23 of the outbreak and requested that each unit investigate for potentially linked cases in their area. Persons identified through the above means were contacted by the BGOSHU, and other local health units by telephone. The purpose of these interviews was to determine the date of onset of illness, if water was consumed and where, and potential food exposures.

A standardized questionnaire was developed to record information during the telephone interview. This included pertinent identifiers, date and time of symptom onset, location of any food establishments where the individual may have eaten in the four days prior to symptom onset, exposure to Walkerton water, changes in symptoms since their visit to the emergency unit and whether a stool specimen was collected. This information was collected for each family member who was exhibiting symptoms and entered into Microsoft Excel 97™ software.

After the investigation had ruled out the likelihood of a common food source, the telephone survey was revised (Appendix D) to include more specific questions about Walkerton water exposure. Other information included whether the case was primary or secondary (see definition below), development of HUS, whether an emergency room visit was made, if and when hospitalization occurred, the name and location of the hospital, and whether a stool sample was collected.
Three attempts were made to contact each individual. If that person or family could still not be reached or if additional information was outstanding, a letter was sent with a request to contact the Health Unit. A deadline of August 31, 2000 was set and any persons not contacted or with outstanding information were classified accordingly.

Extensive data verification was conducted prior to analysis to eliminate duplicate records resulting in the multiple means of case finding.

A suspect case was defined as a person with illness possibly related to the Walkerton outbreak identified to the BGOSHU through hospital reports, laboratory reports or direct notification to a Health Unit.

A case was defined as a person; with diarrhea, or bloody diarrhea; or stool specimens presumptive positive for E. coli O157 or Campylobacter spp. or HUS between April 15 to June 30. For the purposes of attributing cases to the water system, a primary case was defined as a person who had exposure to Walkerton water. A secondary case was defined as a person who did not have any exposure to Walkerton water but had exposure to a primary case defined above. A person was classified as unknown if their exposure status was not indicated.

To confirm the earliest possible date of onset of illness, three cases with reported symptom onset on May 1, May 7 and May 12, and confirmed with a similar strain of E. coli O157:H7 by PFGE were identified. These cases were contacted to verify onset dates, symptoms and exposure to Walkerton water.
5.1.2 Results
As of August 31, 2000, 1730 suspect cases were identified and an effort was made to contact each individual by telephone or mail. Of these, 1383 (80%) were found to have illness related to exposure to Walkerton municipal water, 1346 (78%) of whom met the definition of a case described in Section 5.1.1. The 37 individuals who were not defined as a case were those who did not have diarrhea or a stool culture positive for *E. coli* O157 or *Campylobacter* spp. Two hundred and three (12%) were found to be unrelated to the Walkerton outbreak or not ill. One hundred and forty four (9%) could not be contacted.

5.1.2.a Description of Cases
The following analysis describes those who met the definition of a case. Onset of illness ranged from April 15 to June 27. There were two peaks in numbers of cases: the first occurred between May 17 and May 19, while the second occurred between May 22 and May 24 (see Figure 2). In the figure, the culture confirmed group is defined as a stool culture positive for *E. coli* O157, or *Campylobacter* spp (n=273). Culture negative included persons whose stool specimens were negative for these pathogens (n=394). Not tested cases did not submit a stool specimen for culture (n=668).

![Figure 2](image)

**Figure 2**
**Descriptive Study - Date of Illness Onset for Reported Cases**
Walkerton, Ontario, April - June, 2000

Number of cases (n=1335), Date of onset missing for 11 reported cases

- **Culture confirmed**
- **Culture negative**
- **Not tested**
Residents who lived within Walkerton or its boundary would have had the potential for daily exposure. Analysis of cases who were “true” visitors to Walkerton (stayed for only a day or for a specified period of time) showed a wide range of exposure dates, ranging from mid April to June. However, approximately one-third of visitor cases were in Walkerton over the weekend between May 12 to 14 (20% on May 14 only). Almost three quarters of visitor cases were in Walkerton between May 12 to May 21.

The age distribution of reported cases is shown in Figure 3. The median age of cases was 29 years (mean: 31 years, range <1 to 97 years) and 58% were female. Seven hundred and fifty-one cases (56%) visited the emergency room and 65 (5%) were admitted. Twenty-seven cases (2%) developed HUS. None of the cases developed thrombotic thrombocytopenic purpura (TTP). Six people (0.4%) died as a result of this outbreak.
Table 1 summarizes the illness profile of cases. Ninety-seven percent of all cases were classified as primary, 3% as secondary and 0.2% as unknown. The most predominant symptom was diarrhea, followed by cramps, fever and vomiting. Just under one-third (30%) of cases had bloody diarrhea. Half of the cases submitted a stool sample for testing. Detailed laboratory results are also described in the table below.

**Table 1**

**Illness Profile of Cases (n=1346)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case Status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>1304</td>
<td>96.90</td>
</tr>
<tr>
<td>Secondary</td>
<td>39</td>
<td>2.90</td>
</tr>
<tr>
<td>Unknown</td>
<td>3</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>Symptom</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diarrhea</td>
<td>1296</td>
<td>96.30</td>
</tr>
<tr>
<td>Bloody Diarrhea</td>
<td>400</td>
<td>29.70</td>
</tr>
<tr>
<td>Cramps</td>
<td>993</td>
<td>73.80</td>
</tr>
<tr>
<td>Fever</td>
<td>510</td>
<td>37.90</td>
</tr>
<tr>
<td>Vomiting</td>
<td>323</td>
<td>24.00</td>
</tr>
<tr>
<td><strong>Stool Test Results</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Submitted a stool sample</td>
<td>675</td>
<td>50.10</td>
</tr>
<tr>
<td>Negative result</td>
<td>383</td>
<td>28.50</td>
</tr>
<tr>
<td>Positive for <em>E. coli</em> O157</td>
<td>163</td>
<td>12.10</td>
</tr>
<tr>
<td>Positive for <em>C. jejuni</em></td>
<td>97</td>
<td>7.20</td>
</tr>
<tr>
<td>Positive for <em>C. coli</em></td>
<td>7</td>
<td>0.50</td>
</tr>
<tr>
<td>Positive for both <em>C. jejuni</em> and <em>C. coli</em></td>
<td>1</td>
<td>0.07</td>
</tr>
<tr>
<td>Positive for both <em>E. coli</em> O157 and <em>Campylobacter</em> spp.</td>
<td>11</td>
<td>0.80</td>
</tr>
<tr>
<td>Verotoxin positive only</td>
<td>2</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Symptoms of cases with *E. coli* O157 infection only (n=163) were as follows: diarrhea (92%), bloody diarrhea (56%), cramping (74%), fever (41%) and vomiting (31%). The median age of *E. coli* O157 infected cases was 6 years (mean: 18 years, range <1 to 91 years). Fifty-one percent of cases were female.

*E. coli* O157 isolates with the phage type 14 were found in the majority of cases (n=147). Isolates with phage type 14a were found in three additional cases. The PFGE pattern A (genetic fingerprint) was found in 150 of *E. coli* O157 patient isolates. Pattern A1 and A4 (genetically closely related to pattern A) were found in two additional cases respectively. The majority of *E. coli* O157 isolates tested for verotoxin genotype were found to be verotoxin 2 (VT2).

Symptoms of cases infected with *Campylobacter* spp. only (n=105) were as follows: diarrhea (95%), bloody diarrhea (34%), cramping (75%), fever (57%) and vomiting (22%). Cases were a median age of 34 years (mean: 38 years, range 1 to 91 years) Fifty percent of cases infected with *Campylobacter* spp. were female.
The majority of isolates from cases with *C. jejuni* infection had the phage type 33 (n=56). These isolates were further serotyped and found to have a similar surface antigenic profile.

Eleven cases were positive for other organisms including five different serotypes of *Salmonella*, *Yersinia enterocolitica*, *A. hydrophila*, and *A. caviae*. These people also had exposure to the Walkerton municipal water and experienced diarrheal illness. Although classified as cases in the descriptive study based on exposure and symptoms, it was impossible to determine the true cause of their illness.

### 5.1.2.b Hospital Admissions

Overall, 65 persons were admitted to hospital; however, telephone interviews were only conducted for 59 cases described below.

The median age of hospitalized patients was 8 years (mean: 26 years, range 1 to 93 years). Most of these were children under nine years of age (55%). Fifty-four percent of patients were female. Onset of symptoms for hospitalized patients ranged from May 14 to June 9, 2000.

Of 50 hospitalized patients with a stool culture, four were positive for *C. jejuni*, 40 patients were positive for *E. coli* O157:H7, and one patient was co-infected with *E. coli* O157:H7 and *C. coli*.

### 5.1.2.c Haemolytic Uremic Syndrome (HUS) Cases

Twenty-seven hospitalized patients developed HUS. The median age was 4 years (mean: 22 years, range 1 to 85 years). Fifty-two percent of the HUS cases were between 1 to 4 years. Fifty-two percent were female. Symptoms of cases that went on to develop HUS were as follows; 23 (85%) had diarrhea, 17 (63%) bloody diarrhea, 14 (52%) cramping, 10 (37%) fever and 10 (37%) had vomiting.

Two HUS cases confirmed with *C. jejuni* infection while 22 had *E. coli* O157:H7 infection.

### 5.1.2.d Deaths Related to the Outbreak

Six people died as a result of this outbreak, five of whom had HUS. Five of those who died were Walkerton residents. Stool cultures showed that two of these patients were infected with *C. jejuni* and three were infected with *E. coli* O157:H7.
5.1.2.e Geographic Distribution of Cases

One thousand two hundred and thirty-eight individuals (92%) were residents from the BGOSHU area. The remaining 8% resided in 18 different Health Unit regions across Ontario. These are listed below. Two persons lived out of province; one in Manitoba and Alberta, respectively.

Table 2  
Cases by Health Unit of Residence

<table>
<thead>
<tr>
<th>Health Unit</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruce-Grey-Owen Sound Health Unit</td>
<td>1238</td>
<td>92.0</td>
</tr>
<tr>
<td>Regional Municipality of Waterloo, Community Health Department</td>
<td>26</td>
<td>1.9</td>
</tr>
<tr>
<td>Wellington-Dufferin-Guelph Health Unit</td>
<td>21</td>
<td>1.6</td>
</tr>
<tr>
<td>Huron County Health Unit</td>
<td>10</td>
<td>0.7</td>
</tr>
<tr>
<td>Simcoe County District Health Unit</td>
<td>9</td>
<td>0.7</td>
</tr>
<tr>
<td>Lambton Health Unit</td>
<td>9</td>
<td>0.8</td>
</tr>
<tr>
<td>Perth District Health Unit</td>
<td>7</td>
<td>0.5</td>
</tr>
<tr>
<td>Halton Regional Health Department</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td>Middlesex-London Health Unit</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td>Regional Municipality of Peel Health Department</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Haliburton-Kawartha Pine Ridge District Health Unit</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Elgin St. Thomas Health Unit</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Toronto Public Health</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>York Regional Health Services Department</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Region of Hamilton-Wentworth Social Services and Public Health Services</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Division</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chatham-Kent Health Unit</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Regional Niagara Public Health Department</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Oxford County Board of Health</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Windsor-Essex County Health Unit</td>
<td>1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Of all cases, 871 (65%) had a Walkerton address. 799 (59%) lived at an address which was supplied with Walkerton municipal water, 67 (5%) lived at a rural route address and 5 (0.4%) had an unknown address. As defined in section 5.1.1, all cases who did not live in Walkerton were epidemiologically linked to the Walkerton outbreak.
5.2 SPATIAL DISTRIBUTION OF CASES

To describe both the geographic and temporal distribution of gastroenteritis cases associated with the outbreak, a number of maps were created.

5.2.1 Methods

Cases used in this analysis were identified and defined in Section 5.1.1. A latitude and longitude were assigned to as many Walkerton cases as possible using the following geocoding methods:

- Enhancing a commercially available street network file (CanMap™ 2.0, Desktop Mapping Technologies inc.)
- Standardizing and cross-referencing case addresses with the help of a digital telephone directory (Select Phone™, Pro CD)
- Merging the enhanced street network file with the standardized case file.

Enhancement of the CanMap™ digital street network file involved the addition of new streets and refinement of street address ranges. Most of Walkerton is on a 100 block system, with addresses increasing by 100 each block. CanMap™ provides coordinates for 100 theoretical residences per block, equally spacing residences within the block. In reality, however, the address ranges were much smaller. The spatial accuracy of the geocoding process was greatly enhanced by limiting the range of addresses per block by the actual addresses. New streets and the enhanced address ranges were verified by a detailed street-by-street survey of the town.

The addresses of all cases were individually reviewed and standardized to allow for electronic linking to the enhanced street network file. Because the linking process involved a probability-matching algorithm, all addresses needed to be standardized. For example, 2nd street needed to be changed to Second Str., etc. When possible, cases without an address were assigned addresses based on additional family information (e.g. sibling address was available) or telephone directory information. Telephone numbers were available for all cases, and using an electronic telephone directory (Select Phone™), addresses could be assigned to each telephone number.

The Geographic Information System (GIS) software used for geocoding and mapping was Arcview 3.2 (Environmental Systems Research Institute, Inc.).
5.2.2 Results
Of the 799 cases who were Walkerton and whose homes were supplied with municipal water, 788 were successfully mapped by date of onset. Addresses were missing, or could not be geocoded for 4 cases, and date of onset was missing for 7 additional cases. Mapping the cases by date of onset showed no specific pattern within the town by location (Appendix E). Figure 4 plots all cases by stool culture results and illustrates the widespread distribution of cases within the town.
5.3 PHYSICIAN SURVEY

5.3.1 Methods
To determine whether there were any cases which might have sought medical attention prior to the date when patients went to the emergency department of their local hospital, a physician survey was conducted. The survey (Appendix F) was designed to identify cases of gastrointestinal illness with onset of symptoms between May 8 to May 16, who visited a general practitioner.

The seven general practitioners offices within the town of Walkerton were contacted by telephone between June 5 and June 19, 2000. A letter outlining the study objectives and the survey was faxed to each office for completion. Physicians were asked to record the following information for each patient: name, address, phone number, date of birth, gender, symptoms, date of onset, date of visit, and stool culture results, and to fax the completed survey to the BGOSHU. Those who did not respond to the survey were followed up by telephone.

5.3.2 Results
Six of the seven general practitioners responded to the survey. Between May 8 and May 16, one physician reported seeing a patient with chronic diarrhea, another had seen a patient with cramps and vomiting with an onset of May 3, while a third had seen a patient with an onset of bloody diarrhea of May 15. This person had also visited the emergency room.

5.4 CONCLUSIONS

In the descriptive study, 1346 people were identified with illness related to the Walkerton outbreak, most of whom resided in the Town of Walkerton and would have been at greatest risk of exposure to the contaminated water supply. The illnesses spanned a period of 2.5 months, with the majority occurring between May 17 and 19. With an average incubation period of three to four days, the predominant exposure dates would be between May 13 and 16. This finding was supported by the fact that approximately one-third of the visitors to Walkerton were there on May 12 to 14. The number of illnesses dropped substantially within five days of the Boil Water Advisory being issued.

The identification of ill patients with onset of symptoms in mid to late April suggests possible contamination of the municipal water system prior to the middle of May, although the physician survey indicated that physicians saw few cases of gastrointestinal illness in between May 8 and 16. This will be discussed further in Section 9.0.

The outbreak affected all age groups with the majority reported among children aged 1 to 9 years, and adults aged 30 to 49 years. The impact of the outbreak was severe, as shown by the number of hospitalized patients, HUS patients, and the loss of lives. Patients infected with *E. coli* O157:H7 were more likely to exhibit symptoms of
bloody diarrhea, and be hospitalized, or develop HUS than those infected with *Campylobacter* spp. Subtyping of the *E. coli* O157:H7 and *Campylobacter* spp. isolates using several different methods showed the isolates from different patients were genetically related, suggesting a common origin.

The mapping of cases by date of onset showed the contamination was not limited to one area of the municipal water distribution system, but was spread throughout. This accounts for the reporting of cases in all parts of the town.
6.0 CROSS-SECTIONAL STUDY

6.1 CROSS-SECTIONAL STUDY

6.1.1 Methods
In brief, the cross-sectional study involved surveying a random sample of households within the postal code region of Walkerton. The purpose was to make statistical comparisons between ill and non-ill persons to identify potential risk factors for illness, and establish population-based estimates of illness for the Town of Walkerton.

6.1.1a Survey Design
Two structured questionnaires, a household and individual telephone survey (Appendix G and H) were developed. The household questionnaire was designed to gather information on the number of people in the household, demographic information for each individual, farm and livestock exposure, the type and number of pets and whether the pets had diarrhea, contacts with nursing homes and daycare institutions, source of tap water, and use of home water treatment systems.

The individual questionnaire was designed to collect information on clinical history, use of antibiotic and anti-diarrheal medication, and water and non-water exposures. Questions about potential exposures referred to the time period 10 days prior to development of diarrhea for ill respondents and between May 8 and May 18 for non-ill respondents. Specific water exposures included home water use and exposures to other potential sources of Walkerton water from work or school, water fountains, restaurants, and private homes. Questions were also asked to clarify when and how residents heard about the Boil Water Advisory, and what measures residents took to protect themselves after the Boil Water Advisory was issued.

During the interview process, interviewers spoke with a head of the household to collect information for the household questionnaire. Then all adults 15 years of age and older in the household were interviewed using the individual questionnaire. Parents or guardians acted as proxy respondents for children under 15 years of age.

Telephone interviews were conducted by 14 staff from the BGOSHU, 4 staff from the Wellington-Dufferin-Guelph Health Unit, 8 staff from the Huron County Health Unit and the Telephone Survey Unit in London (co-ordinated by the Middlesex-London Health Unit) between June 1 and June 13, 2000. Each group received interviewer training prior to starting the interview process. Each interviewer made at least three attempts to contact all households on their list.

The sampling frame for the study included all listed telephone numbers from Select Phone™ software for people with a Walkerton postal code. This subset was exported into Microsoft Excel 97™ software. Residents from the home for the aged, and the retirement home in Walkerton were included, while business and fax numbers were removed. It was estimated that a sample size of 400 households would be needed.
To account for non-response and out of service numbers, a random sample of 627 households was generated in Microsoft Excel 97™ software.

Interviewers were given names and phone numbers of individuals they were not to contact. This list included those who were hospitalized, in critical condition or had died. If any of these persons were on the list, they were to be removed from the sample.

Data were entered into Epi Info 6.04b. To reduce coding errors, all questionnaires were double entered in Epi Info and verified using the “Validate data entry” function. Analysis was conducted using SPSS™ Version 10.0.5 software for descriptive and univariate analysis and, SAS™ Version 8.0 software for multivariate analysis.

6.1.1.b Definitions
A case was defined as a person who had; three or more loose stools within a 24 hour period, or had any amount of bloody diarrhea since May 1, or had laboratory confirmed E. coli O157 or Campylobacter spp. in stool specimens. A control was defined as a person who had not experienced any symptoms of diarrhea since May 1. Persons with symptoms of diarrhea but not meeting the case definition were excluded from the analysis.

For this analysis, the first case in a household, with known onset date, was designated as a primary case, as were any others with onset within 3 days of the first case. Otherwise, other household cases were designated as secondary cases. Cases with unknown date of onset were neither primary nor secondary cases (status unknown). This definition was more specific than the definition used in the descriptive analysis to ensure that only true primary cases were used.

6.1.1.c Univariate, Multivariate and Dose Response Analyses
In the univariate analysis, all water and non-water exposures were cross-tabulated with the case variable to determine significant associations. Significantly associated exposures were also stratified by age group, sex, and regular home water source (Walkerton municipal supply vs. other water source).

In the multivariate analysis, the association between exposures and the case variable case were examined using logistic regression. Any exposures with a p-value less than 0.25 in the univariate analysis were considered for inclusion in the model. All non-significant exposures were removed from the model after assessment for confounding affect on the water exposure variables. The fit of continuous and multilevel exposure variables was assessed using categorical indicator variables. If the indicator variable showed a linear response, the single exposure variable was used. All first order interactions of remaining exposures were assessed for significance. As the subjects in this study were selected by household, generalized estimating equation (GEE) regression model with exchangeable correlation structure was used to adjust for correlation within households (SAS, Proc GENMOD). Dose response was modelled
as described above, using the quantitative data on water consumption in the home, at
work or school.

6.1.2 Results
6.1.2.a Respondents
Six hundred and twenty seven households were on the initial contact list. Interviews
were completed for a total of 367 households and 899 persons. Of the remaining 260
households, 106 could not be contacted, 75 refused to participate, 69 were unable to
be contacted due to changes in phone numbers, 4 were businesses, 2 were removed
from the list as sensitive households (at least one household person was in critical
condition in hospital or had died), 2 were not called, while 2 remained unaccounted
for. A calculation of the statistical power showed that a relative risk of 2.7 could be
demonstrated with a sample size of 365 households (assuming 80% power and 95%
confidence intervals).

Three households (10 persons) were excluded from the data set as their current
residence was found to be outside of the sampling frame. Three hundred and sixty-
four households and 889 individuals remained in the following analysis.

The age and gender distribution of respondents within the Town of Walkerton was
similar to distributions of age and gender from the 1996 census. There were no
statistically significant differences by age group or gender.

6.1.2.b Household Survey
There was a median of two persons per household. Seventy-six households (21%)
were on farms and of these, 35 (46%) had livestock. The type of livestock was as
follows; cattle, 23 (66%); horses, six (17%); goats, sheep or llama, seven (20%); pigs
four, (11%); poultry, two (6%); and donkey, one (3%).

Twenty-five (7%) households had at least one member who attended a day care
between Monday May 1 and Sunday May 21. Fifty-eight (16%) households had at
least one member who worked at a nursing home or other institution between
Monday May 1 and Sunday May 21.

One hundred and eighty-one households (50%) had pets in the home. Of these, 123
(70%) had dogs and 109 (60%) had cats. Fifteen (8%) households reported that their
pet had been ill with diarrhea since May 1. This included 12 dogs, two cats and one
unknown pet. Dates of onset of diarrhea ranged from May 1 to June 4.

Each household was asked to report the usual source of tap water in the house
between Monday, May 1 and Sunday, May 21. Two hundred and forty-eight
households (68%) used the Walkerton municipal supply as their usual source of tap
water. One hundred and four (29%) use single or multiple private wells, and 12 (3%)
used another source. Only 5 households reported the other source and these included
community well, Mildmay water, private shared source, rainwater, and trailer park.
Twenty-nine households (8%) reported using a home water treatment system. This was defined as a system, which treated all water coming into the home. It did not include systems, which treated only water for one tap or sink.

One hundred and sixty-four households reported having out of town guests between Monday, May 1 and Sunday, May 21. The names of guests and their phone numbers were collected from those households who were willing to provide these data. After collection, this information was provided to the BGOSHU.

One hundred and twenty-three (34%) households had at least one person with a family member who fit the case definition. They are described as ill households in the following household analysis. The average number of persons per household was 3.2 for ill households and 2.5 for non-ill households.
Table 3 compares characteristics between the ill and non-ill households and shows differences between the two groups. The proportion of households that were on farms was significantly different between ill and non-ill households (Yates p=0.0052), with less ill households on farms than in town.

The proportion of ill and non-ill households that had family members who worked at or attended a day care, worked at a nursing home or institution, had pets in the home and had ill pets were similar.

Eighty four percent of ill households had Walkerton municipal water as their usual source of water compared to only 60% of non-ill households. This difference was statistically significant (Yates p =< 0.0001).

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Comparisons of characteristics between ill and non-ill households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
<td>Ill Household (n=123)</td>
</tr>
<tr>
<td>Live on a farm</td>
<td></td>
</tr>
<tr>
<td>• Yes</td>
<td>15 (12.2%)</td>
</tr>
<tr>
<td>• No</td>
<td>108</td>
</tr>
<tr>
<td>Exposure to livestock on farm</td>
<td></td>
</tr>
<tr>
<td>• Yes</td>
<td>7 (5.7%)</td>
</tr>
<tr>
<td>• No</td>
<td>111</td>
</tr>
<tr>
<td>Family member attendance at day care</td>
<td></td>
</tr>
<tr>
<td>• Yes</td>
<td>13 (10.6%)</td>
</tr>
<tr>
<td>• No</td>
<td>110</td>
</tr>
<tr>
<td>Family member work at nursing home or institution</td>
<td></td>
</tr>
<tr>
<td>• Yes</td>
<td>23 (18.7%)</td>
</tr>
<tr>
<td>• No</td>
<td>100</td>
</tr>
<tr>
<td>Pets at home</td>
<td></td>
</tr>
<tr>
<td>• Yes</td>
<td>64 (52.0%)</td>
</tr>
<tr>
<td>• No</td>
<td>59</td>
</tr>
<tr>
<td>Ill pets at home</td>
<td></td>
</tr>
<tr>
<td>• Yes</td>
<td>8 (6.5%)</td>
</tr>
<tr>
<td>• No</td>
<td>112</td>
</tr>
<tr>
<td>Water Source</td>
<td></td>
</tr>
<tr>
<td>• Walkerton</td>
<td>103 (83.7%)</td>
</tr>
<tr>
<td>• Other</td>
<td>20</td>
</tr>
</tbody>
</table>
6.1.2.c Individual Survey
Two hundred and thirty eight individuals (27%) reported some diarrheal illness, while 650 reported no diarrheal illness since May 1. One person did not know their illness status and was excluded from further analysis.

One hundred and eighty-one respondents (20.4%) met the case definition. Of these, 150 (82.9%) were primary cases, 29 (16%) were secondary and 2 were unable to be classified. Figure 5 shows the number of cases by date of onset of diarrhea. The main peak of illness occurred on May 17. A second peak, on May 25 contained equal numbers of primary and secondary cases.

Figure 5
Cross-Sectional Study, Date of Onset of Diarrhea
Walkerton, Ontario, May - June, 2000

For the remainder of this analyses, primary cases (n=150) and controls (n=650) are compared.
Table 4 shows the demographic characteristics of cases and controls. The distribution of cases and controls by age was similar. Although there was a higher percentage of cases in the 5 to 14 age group, this difference was not statistically significant. The mean age of cases was significantly lower (34 years) than that of controls (39 years), (p=0.0099). Distributions by gender were similar.

Table 4
Characteristics of Cases and Controls

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cases (n=150)</th>
<th>Controls (n=650)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percent</td>
</tr>
<tr>
<td>Age Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-4</td>
<td>7</td>
<td>4.8</td>
</tr>
<tr>
<td>5-9</td>
<td>19</td>
<td>13.1</td>
</tr>
<tr>
<td>10-14</td>
<td>18</td>
<td>12.4</td>
</tr>
<tr>
<td>15-19</td>
<td>14</td>
<td>9.7</td>
</tr>
<tr>
<td>20-29</td>
<td>4</td>
<td>2.8</td>
</tr>
<tr>
<td>30-39</td>
<td>19</td>
<td>13.1</td>
</tr>
<tr>
<td>40-49</td>
<td>27</td>
<td>18.6</td>
</tr>
<tr>
<td>50-59</td>
<td>15</td>
<td>10.3</td>
</tr>
<tr>
<td>60-69</td>
<td>16</td>
<td>11.0</td>
</tr>
<tr>
<td>70-79</td>
<td>5</td>
<td>3.4</td>
</tr>
<tr>
<td>80 and up</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>Missing</td>
<td>5</td>
<td>3.4</td>
</tr>
<tr>
<td>Mean Age (years)</td>
<td>33.6</td>
<td></td>
</tr>
<tr>
<td>Median Age (years)</td>
<td>36.0</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>1-83</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>66</td>
<td>44.0</td>
</tr>
<tr>
<td>Female</td>
<td>84</td>
<td>56.0</td>
</tr>
<tr>
<td>Missing</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Table 5 summarizes the symptoms, burden of illness indicators and interventions taken by primary cases.

### Table 5: Description of Primary Case Illness (n=150)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symptom</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diarrhea (by definition)</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Blood in stool</td>
<td>34</td>
<td>23</td>
</tr>
<tr>
<td>Abdominal cramps</td>
<td>129</td>
<td>86</td>
</tr>
<tr>
<td>Fever</td>
<td>55</td>
<td>37</td>
</tr>
<tr>
<td>Vomiting</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td><strong>Duration of illness (n=101)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean number of days</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>Median number of days</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>1-23</td>
<td></td>
</tr>
<tr>
<td><strong>Days unable to carry out regular activities (n=145)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean number of days</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Median number of days</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>0-18</td>
<td></td>
</tr>
<tr>
<td><strong>Quantity of stools in 24 hour period (n=141)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean number of stools</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Median number of stools</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>3-30</td>
<td></td>
</tr>
<tr>
<td><strong>Outcomes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did not seek any medical attention</td>
<td>70</td>
<td>46.6</td>
</tr>
<tr>
<td>Phoned a health care professional</td>
<td>47</td>
<td>31.3</td>
</tr>
<tr>
<td>Visited emergency</td>
<td>43</td>
<td>28.7</td>
</tr>
<tr>
<td>Visited a doctor</td>
<td>28</td>
<td>18.7</td>
</tr>
<tr>
<td>Admitted to hospital</td>
<td>2</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Stool Culture</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. coli O157 positive</td>
<td>8</td>
<td>5.3</td>
</tr>
<tr>
<td>Campylobacter spp. Positive</td>
<td>12</td>
<td>8.0</td>
</tr>
<tr>
<td><strong>Took antibiotics for diarrhea</strong></td>
<td>4</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Anti-diarrheals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Took any anti-diarrheal</td>
<td>41</td>
<td>27.3</td>
</tr>
<tr>
<td>Took Immodium</td>
<td>14</td>
<td>9.3</td>
</tr>
<tr>
<td>Took Kaopectate</td>
<td>7</td>
<td>4.7</td>
</tr>
<tr>
<td>Took Lomotil</td>
<td>3</td>
<td>2.0</td>
</tr>
<tr>
<td>Took other over the counter medication (Pepto Bismol)</td>
<td>20</td>
<td>13.3</td>
</tr>
<tr>
<td><strong>Took antibiotics for other reason since April 1</strong></td>
<td>14</td>
<td>9.3</td>
</tr>
</tbody>
</table>
6.1.2.d Univariate analysis

To determine which exposures were associated with illness, water and non-water exposure variables were cross-tabulated by case status. Tables 6, 7 and 8 describe the relative risk associations and p-values of non-water exposures, and water exposures and illness. Yates p-values are reported in the following tables unless specified otherwise.

Table 6
Associations between Non-Water Exposures and Illness

<table>
<thead>
<tr>
<th>Variable</th>
<th>RR</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ate hamburger or ground beef †</td>
<td>0.75</td>
<td>0.1071</td>
</tr>
<tr>
<td>Ate chicken †</td>
<td>0.72</td>
<td>0.0712</td>
</tr>
<tr>
<td>Ate salami †</td>
<td>0.60</td>
<td>0.0537</td>
</tr>
<tr>
<td>Ate meat †(salami, chicken, or beef)</td>
<td>0.60</td>
<td>0.0560</td>
</tr>
<tr>
<td>Ate alfalfa sprouts †</td>
<td>1.34</td>
<td>0.5188 *</td>
</tr>
<tr>
<td>Drank fresh unpasteurized juice †</td>
<td>1.07</td>
<td>0.9834</td>
</tr>
<tr>
<td>Contact with livestock †</td>
<td>0.42</td>
<td>0.0008</td>
</tr>
<tr>
<td>Horses †</td>
<td>1.28</td>
<td>0.5696 *</td>
</tr>
<tr>
<td>Cows †</td>
<td>0.31</td>
<td>0.0006</td>
</tr>
<tr>
<td>Poultry †</td>
<td>0.53</td>
<td>0.6976 *</td>
</tr>
<tr>
<td>Goats, sheep or llamas †</td>
<td>0.23</td>
<td>0.0997 *</td>
</tr>
<tr>
<td>Donkeys †</td>
<td>0.00</td>
<td>1.0000 *</td>
</tr>
<tr>
<td>Pigs †</td>
<td>0.26</td>
<td>0.1479 *</td>
</tr>
<tr>
<td>Worked at an abattoir, slaughter house or butcher shop †</td>
<td>0.66</td>
<td>1.0000 *</td>
</tr>
<tr>
<td>Travelled outside of Canada †</td>
<td>0.37</td>
<td>0.4879 *</td>
</tr>
<tr>
<td>In contact with individuals outside of household ill with diarrhea †</td>
<td>1.21</td>
<td>0.2666</td>
</tr>
<tr>
<td>Regular contact with livestock since Jan 1, 2000</td>
<td>0.44</td>
<td>0.0019</td>
</tr>
<tr>
<td>Live on a farm</td>
<td>0.37</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Exposed to livestock on a farm</td>
<td>0.39</td>
<td>0.0086</td>
</tr>
<tr>
<td>Family member worked at or attended at day care between May 1 – 21</td>
<td>1.49</td>
<td>0.1077</td>
</tr>
<tr>
<td>Family member worked at a nursing home or other institution between May 1-21</td>
<td>0.91</td>
<td>0.7326</td>
</tr>
<tr>
<td>Have dogs or cats as pets</td>
<td>0.84</td>
<td>0.2788</td>
</tr>
<tr>
<td>Have dogs or cats ill with diarrhea since May 1</td>
<td>1.62</td>
<td>0.0946</td>
</tr>
</tbody>
</table>

* Referent time period is 10 days prior to onset of diarrhea for cases and between May 8 and May 18 for controls
2 Meat exposure was defined as anyone who responded “yes” to consuming beef, chicken or salami..
*2 sided Fisher Exact Test p value 2 sided
### Table 7
Associations between Walkerton Municipal Water Exposures\(^1\) and Illness

<table>
<thead>
<tr>
<th>Variable</th>
<th>RR</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed drinking water directly from the tap or filtered at home(^2)</td>
<td>2.79</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Consumed juice made with water directly from the tap or filtered at home(^2)</td>
<td>1.68</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Consumed drink mixes made with water directly from the tap or filtered from home(^2)</td>
<td>1.78</td>
<td>0.0022</td>
</tr>
<tr>
<td>Consumed coffee made with water directly from the tap or filtered from home(^2)</td>
<td>1.29</td>
<td>0.1141</td>
</tr>
<tr>
<td>Consumed tea made with water directly from the tap or filtered from home(^2)</td>
<td>1.19</td>
<td>0.3664</td>
</tr>
<tr>
<td>Consumed alcoholic beverages mixed with water directly from the tap or filtered from home(^2)</td>
<td>1.30</td>
<td>0.6033</td>
</tr>
<tr>
<td>Consumed tap water or beverages mixed with water at work or school</td>
<td>1.49</td>
<td>0.0087</td>
</tr>
<tr>
<td>Consumed water from a Walkerton water fountain</td>
<td>1.46</td>
<td>0.0554</td>
</tr>
<tr>
<td>Consumed unbottled water or beverages mixed with water at any Walkerton restaurant</td>
<td>1.95</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Consumed tap water, or other beverages mixed with water at any private Walkerton home besides own home</td>
<td>2.02</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Consumed ice made with water directly from the tap or filtered at home(^2)</td>
<td>2.03</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Brushed teeth with water directly from the tap or filtered at home(^2)</td>
<td>3.14</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Washed fruits or vegetables with water directly from the tap or filtered at home(^2)</td>
<td>2.22</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Washed hands with water directly from the tap or filtered at home(^2)</td>
<td>3.20</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Consumed any Walkerton water(^4)</td>
<td>6.99</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Indirect contact with Walkerton water (excludes ice cubes)(^4)</td>
<td>3.24</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Use Walkerton municipal water as main supply at home</td>
<td>3.37</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

---

\(^1\) Referent time period is exposure 10 days before onset of diarrhea for cases and between May 8 and May 18 for controls.

\(^2\) Defined as “Yes” when respondents used Walkerton municipal water directly from the tap or filtered from the tap (e.g. Brita filter) at home.

\(^3\) Defined as “Yes” when respondents consumed Walkerton municipal water directly from the tap or filtered from the tap (e.g. Brita filter) at home in a glass of water, juice, crystal drink mix, alcoholic beverage, in ice, or if they answered “Yes” to water consumption at any of the following locations; work or school, Walkerton water fountain, Walkerton restaurants, or private Walkerton home.

\(^4\) Defined as “Yes” when respondents used Walkerton municipal water directly from the tap or filtered from the tap (e.g. Brita filter) at home to brush teeth, wash fruits or vegetables, or wash hands.
Table 8
Association between Recreational Walkerton Municipal Water Exposures and Illness in Children Aged 14 years or Younger

<table>
<thead>
<tr>
<th>Variable</th>
<th>RR</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Played in a wading pool filled with water directly from the tap or filtered from home</td>
<td>1.37</td>
<td>0.6917*</td>
</tr>
<tr>
<td>Played in a sprinkler using water directly from the tap or filtered from home</td>
<td>1.49</td>
<td>0.3544</td>
</tr>
<tr>
<td>Played with water balloons using water directly from the tap or filtered from home</td>
<td>2.86</td>
<td>0.0341*</td>
</tr>
<tr>
<td>Played with squirt guns using water directly from the tap or filtered from home</td>
<td>2.62</td>
<td>0.0108*</td>
</tr>
</tbody>
</table>

1 Defined as “Yes” when respondents used Walkerton municipal water directly from the tap or filtered from the tap (e.g. Brita filter).

2 tailed Fisher Exact p value

The following variables were selected for inclusion in the multivariate analysis:
- Consumption of meat
- Exposure to cows
- Exposure to pigs
- Exposure to persons ill with diarrhea outside of household
- Regular contact with livestock since January 1, 2000
- Live on a farm
- Had a member of the family who worked at or attended a day care
- Had pets who were ill with diarrhea from May 1
- Consumed any Walkerton water
- Age Group (grouped by 0-9 years, 10-19 years, 20-59 years and 60 years and older)
- Sex (categorized into male and female)

There were several variables, which assessed exposure to livestock. Exposure to livestock since January 1, 2000 was chosen as the main livestock variable as it would be more representative of regular livestock exposures.
6.1.2.e Multivariate Analysis

From the logistic regression analysis, adjusted for correlation within family, four factors were significantly associated with illness (being a primary case): home water source, Walkerton water consumption, meat consumption and age group (Table 9).

Exposure to Walkerton water was measured by two factors in the model: home water source and consumption of Walkerton water. If all other factors are kept constant, people whose home were supplied with Walkerton water were 2.68 times as likely to be primary cases as people who lived in the area, but had another water supply for their home (e.g. private well). Similarly, people who consumed any Walkerton water were 4.41 times more likely to be primary cases than those who did not consume any were. Combining both factors, people whose homes were on Walkerton municipal water and who consumed Walkerton water were 11.7 times more likely to be primary cases than those who had neither exposure.

People who indicated they had eaten meat (chicken, beef or salami) in the previous 10 days were about half as likely (0.48 times) to become ill as those who had not eaten meat. A similar relationship was noted for each type of meat when analyzed separately.

Older age groups were less likely to become ill than those were in the next lower age group. The youngest group, as expected, was the most likely to be a primary case given the same exposure.

Table 9
Results of Multivariate Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>OR</th>
<th>95% CI of OR</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walkerton water source in home</td>
<td>0.98</td>
<td>2.68</td>
<td>1.53 – 4.71</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Direct exposure to untreated Walkerton water</td>
<td>1.48</td>
<td>4.41</td>
<td>1.46 - 13.31</td>
<td>0.009</td>
</tr>
<tr>
<td>Ate Meat</td>
<td>-0.74</td>
<td>0.48</td>
<td>0.24 - 0.96</td>
<td>0.037</td>
</tr>
<tr>
<td>Age group</td>
<td>-0.30*</td>
<td>0.74</td>
<td>0.60 - 0.91</td>
<td>0.005</td>
</tr>
<tr>
<td>Intercept (baseline)</td>
<td>-2.30</td>
<td>--</td>
<td></td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

* (older age group compared to next younger group: 0-9, 10-19, 20-59, 60+)

6.1.2.f Dose Response

For modelling dose response, 647 cases and controls with complete consumption data regarding the amount of water consumed at home, work or school, were used. When
modelled, the interaction of age and number of glasses of water consumed was highly significant, thus the dose response must be evaluated considering the relationship between these two factors.

Table 10 illustrates that the risk of being a primary case increased within each age group as the average amount of water consumed increased. The highest risk for those with no or low (1 or 2 glasses) Walkerton water consumption was in the oldest age group. However, the highest risk at greater consumption rates was in the younger age groups.

Table 10
Odds Ratios of Illness by Age Group and Average Daily Water Consumption

<table>
<thead>
<tr>
<th>Average glasses</th>
<th>0-9</th>
<th>10-19</th>
<th>20-59</th>
<th>60+</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0</td>
<td>1.5</td>
<td>2.2</td>
<td>3.2</td>
</tr>
<tr>
<td>1</td>
<td>1.8</td>
<td>2.2</td>
<td>2.8</td>
<td>3.4</td>
</tr>
<tr>
<td>2</td>
<td>3.3</td>
<td>3.4</td>
<td>3.6</td>
<td>3.7</td>
</tr>
<tr>
<td>3</td>
<td>5.9</td>
<td>5.2</td>
<td>4.6</td>
<td>4.0</td>
</tr>
<tr>
<td>4</td>
<td>10.6</td>
<td>7.9</td>
<td>5.9</td>
<td>4.4</td>
</tr>
<tr>
<td>5</td>
<td>19.2</td>
<td>12.0</td>
<td>7.5</td>
<td>4.7</td>
</tr>
</tbody>
</table>

1 Baseline category

6.1.2.g Community Response to the Boil Water Advisory
The Boil Water Advisory was issued on May 21 at 1:30 p.m. To assess people’s recall of the Boil Water Advisory, questions were asked about when and how the Boil Water Advisory was heard. Three hundred and ninety-four (44%) respondents reported hearing about the Boil Water Advisory on May 21 (range May 5 to June 21). Three hundred and sixty-three (41%) respondents heard about the advisory from a friend, acquaintance, neighbour or family member, 304 (34%) heard from the radio, 63 (7%) from the TV, two (0.2%) on the news, one by a direct call from the Health Unit and 55 (6%) from other sources. Other sources included work, school, hospital or institution, restaurants and other public areas, e-mail and notice placed in door of home.
Respondents were also asked how they changed their behaviour after the Boil Water Advisory was issued. Although asked of all respondents, the results describe only people whose homes were supplied by Walkerton municipal water.

Table 11
How Residents Changed Behaviour after the Boil Water Advisory was Issued

<table>
<thead>
<tr>
<th>Use of boiled, bottled or non-Walkerton water for...</th>
<th>Always</th>
<th>Usually</th>
<th>Sometimes</th>
<th>Never</th>
<th>Don’t know</th>
<th>Blank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking</td>
<td>566 (94.6%)</td>
<td>11 (1.8%)</td>
<td>8 (1.3%)</td>
<td>4 (0.7%)</td>
<td>0</td>
<td>9 (1.5%)</td>
</tr>
<tr>
<td>Making drinks that are mixed with water</td>
<td>544 (91.0%)</td>
<td>10 (1.7%)</td>
<td>12 (2.0%)</td>
<td>12 (2.0%)</td>
<td>2 (0.3%)</td>
<td>18 (3.0%)</td>
</tr>
<tr>
<td>Brushing teeth</td>
<td>489 (81.8%)</td>
<td>34 (5.7%)</td>
<td>33 (5.5%)</td>
<td>30 (5.0%)</td>
<td>2 (0.3%)</td>
<td>10 (1.7%)</td>
</tr>
<tr>
<td>Washing fruits or vegetables</td>
<td>513 (85.8%)</td>
<td>11 (1.8%)</td>
<td>9 (1.5%)</td>
<td>21 (3.5%)</td>
<td>12 (2.0%)</td>
<td>32 (5.4%)</td>
</tr>
<tr>
<td>Used chlorine treated water for washing hands</td>
<td>488 (81.6%)</td>
<td>35 (5.9%)</td>
<td>16 (2.7%)</td>
<td>50 (8.4%)</td>
<td>0</td>
<td>9 (1.5%)</td>
</tr>
</tbody>
</table>

At least 80% of respondents reported using boiled, bottled or water that was not from Walkerton to drink, make mixed drinks, brush their teeth or wash their fruits and vegetables. Just over 82% of respondents indicated that they used chlorine treated water for washing their hands. Regardless of the recommendations regarding use of Walkerton water, there was still a small proportion of residents who continued to use their home water source for a variety of activities without further treatment.
6.2 COMMUNITY ESTIMATES OF ILLNESS AND UNDER-REPORTING

The objective of this analysis was to estimate the number of Walkerton residents, whose homes were supplied by the municipal water system, that would have become ill from exposure to the contaminated water during the month of May.

6.2.1 Methods

Three data sources were used in this analysis:
- Study participants who lived in Walkerton and whose homes were supplied by Walkerton municipal water, from the cross sectional study
- 1996 Census population by age group
- Ill cases from the descriptive database.

For this analysis, it was assumed that the boundary for the Town of Walkerton used in the 1996 Census reflected only those residents on Walkerton municipal water. Although some residents could have potentially been on a private well within the town, it was unlikely that this would change the final estimates. The estimates of illness were restricted to the month of May since data collection for the cross-sectional study was completed by June 13, and all but four cases identified were ill in May.

Rates of illness by age-category were multiplied by the 1996 Census population and summed to estimate the number of Walkerton residents who would have become ill.

6.2.2 Results

There were 598 Walkerton residents in the cross-sectional study whose home was supplied by Walkerton municipal water. One hundred and fifty-six (26%) were cases, and 442 (74%) were non-cases. This included controls defined in Section 6.1.1.b and respondents who did not meet the case definition.

Table 12 describes the distributions by age of cases and controls that were Walkerton residents whose homes were supplied by Walkerton municipal water and the number of residents expected to become ill.
Table 12
Community Estimates of Illness, May 2000

<table>
<thead>
<tr>
<th>Age Group (years)</th>
<th>Cases (A)</th>
<th>Controls (B)</th>
<th>Total (C)</th>
<th>Percent Ill (D) A/C=D</th>
<th>Expected Population (E) 1996 Census</th>
<th>Expected Ill (F) D*E</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4</td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>33.3%</td>
<td>335</td>
<td>112</td>
</tr>
<tr>
<td>5-14</td>
<td>41</td>
<td>73</td>
<td>114</td>
<td>36.0%</td>
<td>770</td>
<td>277</td>
</tr>
<tr>
<td>15-19</td>
<td>14</td>
<td>44</td>
<td>58</td>
<td>24.1%</td>
<td>335</td>
<td>81</td>
</tr>
<tr>
<td>20-24</td>
<td>4</td>
<td>14</td>
<td>18</td>
<td>22.2%</td>
<td>300</td>
<td>67</td>
</tr>
<tr>
<td>25-54</td>
<td>59</td>
<td>166</td>
<td>225</td>
<td>26.2%</td>
<td>1970</td>
<td>516</td>
</tr>
<tr>
<td>55-64</td>
<td>15</td>
<td>37</td>
<td>52</td>
<td>28.8%</td>
<td>450</td>
<td>130</td>
</tr>
<tr>
<td>65-74</td>
<td>9</td>
<td>41</td>
<td>50</td>
<td>18.0%</td>
<td>425</td>
<td>77</td>
</tr>
<tr>
<td>75 +</td>
<td>2</td>
<td>33</td>
<td>35</td>
<td>5.7%</td>
<td>460</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>151</td>
<td>422</td>
<td>573</td>
<td>5.7%</td>
<td>5035*</td>
<td>1286</td>
</tr>
</tbody>
</table>

Age is missing for 5 cases and 20 controls.
* age specific population counts do not add to the total due to rounding

The crude attack rate of illness was 26.4% (151 cases / 573 total); however, this varied by age and is described in the table above. Overall, we estimate that 1286 cases of Walkerton residents with diarrhea were associated with the outbreak for the month of May. This estimate does not include the background rate of gastroenteritis which we estimate as 7.5% and is similar to previously published studies 22, 23, 24, 25.

In the descriptive study, 740 cases among Walkerton residents were identified with an illness onset during May. If the expected number of ill was 1286, it can be estimated that reports were received from only 58% of the expected cases (740/1286). Thus, 42% were not reported.

Assuming the reporting rate was the same for Walkerton and non-Walkerton residents, and was the same for the duration of the outbreak, the overall estimated number of cases associated with the outbreak is 2321 people.
6.3 CONCLUSIONS

The sample size obtained for the cross-sectional study had the statistical power to identify significant risk factors. The respondents were also representative of the population, as the demographic distribution was comparable to available census data. Analysis of the household level questionnaire identified that households where people became ill were more likely to be supplied by the Walkerton municipal water system and less likely to live on a farm where the water source would be a private supply. These findings were further confirmed and the magnitude of the association quantified through univariate and multivariate analyses. Individuals whose home was supplied with Walkerton municipal water and had consumed Walkerton water were 11.7 times more likely to become ill than those who had neither of these risk factors.

As expected in the analysis of dose-response, risk of illness increased as the number of glasses consumed increased within each age category.

The ill individuals surveyed were younger than the non-ill, as seen in the descriptive study. The illnesses were characterized by diarrhea, often with blood, and severe abdominal cramps. For some individuals, illness lasted for 23 days and prevented them ill from carrying out normal activities for 18 days.

The accuracy of people’s recall of the timing of the Boil Water Advisory was poor, with a wide range of dates reported. In addition, although residents of Walkerton knew of the Boil Water Advisory, some continued to exposure themselves to the water. This raises concern of continued exposure to Walkerton water even after knowledge of the contamination problem. The compliance with the recommendation to wash hands with chlorinated water was high, considering this was an unusual measure done as an extra precaution. This may have contributed to the low rate of secondary cases identified.

The magnitude of the outbreak was demonstrated through the calculation of community estimates which showed in excess of 2300 people may have become ill from exposure to the contaminated municipal water supply in Walkerton.
7.0 ENVIRONMENTAL INVESTIGATION

The purpose of the environmental investigations was to identify how the Walkerton municipal water distribution system became contaminated, and to determine where in the environment the bacteria may have originated.

7.1 REVIEW OF BACTERIAL WATER QUALITY RECORDS

7.1.1 Methods
Bacteriological data from 1990 to 1996, with the exception of 1995, was available through the BGOSHU as part of standard reporting from the Ontario Ministry of Health. After September 1996, routine water testing of municipal water was discontinued by the Ontario Ministry of Health laboratories and subsequently, private laboratories were used. Monthly bacteriological monitoring reports from 1997 to 2000 were provided by the MOE, along with weekly bacteriological test results from January 1 to May 16, 2000.

7.1.2 Results
Review of these data showed no evidence of a particular abnormality with the bacteriological quality of Walkerton’s water. Although, just prior to the outbreak, coliform bacteria were reported in treated water from Well 5 and the distribution system on April 3, 2000. Treated water from Well 5 was also positive for coliform bacteria on April 18 and May 5, however no *E. coli* bacteria were found. On May 16, test results of the treated water at Well 7, and two sites in the distribution system were positive for coliform and *E. coli* bacteria, with both counts in excess of 200 colony forming units /100ml in the well sample. However, the raw water at Well 7 tested negative for any bacteria.

7.2 SUMMARY OF HYDROGEOLOGICAL REPORTS

7.2.1 Methods
Hydrogeological information pertaining to the areas surrounding each of the town wells was obtained from reports prepared when Wells 5, 6 and 7 were established 26, 27, 28, and when the shallow aquifer serving Well 5 was evaluated 29. More current hydrogeological information was available from an interim report prepared by Golder Associates for the Municipality of Brockton as part of the current investigation 30. Since a hydrogeologist was not part of the epidemiological investigation team, comments on the hydrogeological reports will be limited to the bacteriological data presented, and information regarding the potential for surface water and agricultural activity to contaminate the wells.

7.2.2 Results
In a 1978 report, prepared by Ian D. Wilson and Associates, results of an evaluation of a shallow aquifer for its suitability as a site for a new town well were summarized 29. Two shallow test wells were drilled in the vicinity of town Wells 1 and 2, which are no longer in use. Well 5 was later drilled near one of these test
wells. A schematic map of the area showed the well site was bordered by a cow/calf operation to the west and a smaller farm to the south. The test well was drilled directly adjacent to a swampy area. Although it was concluded that a properly constructed well at the site of Test Well 2, along with the existing town wells, could provide a safe perennial water supply, some noteworthy observations were made:

“The water producing zone in Test Well 2 is shallow at 16 to 19 feet and the well is close to a barnyard and swampy area….These facts raise questions as to the suitability of this site as a long term source of supply for the town. Obviously, there is potential for pollution and shallow aquifers can sometimes prove unreliable as sources of supply.”

The report goes on to describe that the cone of influence for the well extends under the barn to the south of the well and likely goes beyond the swamp into the nearby agricultural land. Bacteriological analysis of water from the test well failed to demonstrate fecal coliform bacteria in the water, although coliform bacteria were found (8 bacteria/100ml), and several samples were spoiled due to delays in processing. Subsequent testing, after the construction of Well 5 in June 1978, demonstrated contamination with coliform and fecal coliform counts as high as 12 bacteria/100ml on each test after 48 hours of pumping. Recommendations made by the hydrogeologist to address concerns of environmental contamination included: acquiring additional land to establish a water protection zone, chlorination of the supply and bacterial monitoring.

In 1980, an MOE report of routine inspections of the Walkerton municipal water works noted problems with the bacterial quality of Well 5:

“The bacteriological quality of Well No. 5 reveals a variable bacteria density in the raw water throughout the year. The variation in bacteria density reflects surface activities within the influence of the aquifer. It is recommended that Well No. 5 continue to be monitored on a regular basis in the future to confirm the suitability of the water quality at all times.”

The 1982 hydrogeological report on Well 6, did not describe any major concerns related to nearby agricultural activity, although it did report an elevated nitrate content in the water that was believed to originate from fertilizers used on farms to the west and southwest of the well. The nitrate level did not exceed the recommended guidelines for drinking water. The report raised the concern that the overburden was thin (4–6m) and the well site lands were “low and wet which requires any production well to be isolated from the saturated overburden and surface sources of water.”

Bacteriological testing of Well 6 included only 2 samples compared to 8 samples taken at Well 5 during its construction, however, less than 2 total coliforms and no fecal coliforms were found in the samples tested. Since the well was part of a municipal source, sterilization of the water was recommended. Subsequent to Well 6
coming into production, there were several anecdotal reports and one formal report regarding ponds going dry on area farms. In 1983, investigation of potential interference with an area pond concluded that a test well close to Well 6 may be hydraulically connected to the farm pond and it was recommended that the two test wells in the area be cased and sealed to 12.5m below ground level. According to the interim report prepared by Golder Associates on August 18, 2000, these casings were extended.

Well 7, the main supplier of the town’s water, was constructed in 1987. The hydrogeological report written at the time of construction makes no comment on the bacteriological water quality at the time, although the chemical quality was reported as excellent. The report does not raise any concerns of agricultural activity in the area, but does note that there are nearby swamps and creeks. No interference was found with these water bodies when the new well was pumped. The overburden was again noted to be only 6.1m in depth, but contained clay and stones which reportedly offered protection to the bedrock aquifer. Overall, this well was considered to be an excellent source of large volumes of quality groundwater.

7.3 REVIEW OF WATER FLOW DATA

7.3.1 Methods
Copies of daily, hand written pump house logs for Wells 5, 6 and 7 were obtained for 1991 to May 2000. The 1994 to 2000 data were entered into Microsoft Excel 97 software to facilitate analysis. Computerized data from the Supervisory Control and Data Acquisition (SCADA) system from Wells 5, 6 and 7 which records daily water pumping rates were available for January, February, April and May 2000. SCADA data for March were unavailable due to technical complications. No data were available for months prior to January 2000 due to routine purging of the computer system. Comparisons were made between the log data and the SCADA data to evaluate consistency between the two information sources. These data were also compared to the date of onset of illness of cases identified in the descriptive study to determine which wells were serving the town during the exposure period. Information on local rainfall was also obtained by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) from farmers in the Walkerton area who were part of a monitoring program.

7.3.2 Results
Comparison of pump house logs to SCADA data for April and May 2000 showed comparable outputs for Wells 5 and 6, but major discrepancies for Well 7 in the month of May during the key exposure period for the outbreak (see Figure 6). A similar problem was noted in January and February 2000. Log data indicate that no water was pumped to the town from May 3 to May 9, when the SCADA system indicates that Well 7 was on. The log data indicate that all 3 wells were on from May 9 to May 17, and water flow to the town doubled. The SCADA data indicate that primarily Well 5, with some flow from Well 6 supplied the town between May 8 and
16 with the overall flow remaining consistent with the previous 6 weeks. Both data sources agree that Well 7 was turned off for all of the month of April. According to the well log, Well 7 was turned off on March 10 indicating that Well 7 was off for a total of 51 days. Analysis of well logs back to 1994 indicated that none of the wells were ever off for such an extended period of time in the past. The reason why Well 7 was off on this occasion was unknown to the investigators.
Figure 6
Comparison of Log and SCADA well flows
April & May 2000

Log Data

SCADA Data
Efforts to explain the discrepancies between the log data and the SCADA data failed to reveal evidence of mechanical breakdown in any meter or other equipment. Since the Well 7 log data for May had several readings that were illogical the assumption was made that the SCADA data was a more reliable information source for the critical time period before the outbreak. Figure 7 shows that only Wells 5 and 6 were supplying the town during one median incubation period (3 to 4 days) before the date of onset of the cases. The first cases occurred at the end of April before Well 7 was brought back into service. The majority of the cases occurred between May 16 and May 20, after Wells 5 and 6 had been the source for the town. Heavy rainfall between May 8 and 12 coincided with the period when Wells 5 and 6 were serving the town. Flooding was reported to have occurred in and around Walkerton at the time.
Figure 7
7.4 WATER AND SOIL SAMPLING

7.4.1 Methods
Sampling of 21 sites in the Walkerton water distribution system was conducted by the BGOSHU on May 21, 2000, and continued daily until bacterial counts declined. Sites were chosen based on public access and population at risk; therefore many were restaurants and institutions. Testing of the water samples was conducted by the London Regional Public Health Laboratory. Membrane filtrate culture plates of positive samples of treated water from Well 5 taken on May 23, 2000 by the MOE were transferred to the CPHL for PCR analysis.

On May 30, 2000 one-litre raw water samples were collected from the pump house at Well 5 and Well 7. Well 6 was inaccessible at the time of sampling due to work being done on the well. In addition, one-litre water samples were obtained from a spring next to Well 5, a culvert in the vicinity of Well 6 draining towards Well 6, and the swamp next to Well 7. A water sample was also collected from a pond on a livestock farm close to Wells 6 and 7 that was believed to drain into the swamp adjacent to the municipal wells. These specimens were tested for the presence of *E. coli O157:H7* using the immuno-magnetic separation (IMS) broth enrichment technique. Tests for coliform and *E. coli* bacteria were not conducted on these samples. Soil samples were collected from the vicinity of Well 7 and also tested for the presence of *E. coli O157:H7* using IMS technique.

7.4.2 Results
Of the 21 samples collected and submitted by the BGOSHU, two were positive for coliform and *E. coli* bacteria, with one sample showing a coliform count of >80 bacteria /100 ml and 69 *E. coli* bacteria /100ml. These two sites were persistently positive over several days.

Additional testing of IMS enrichment broth derived from one of the above distribution system samples, and raw and treated water from Well 5 (obtained by the MOE) using PCR identified the presence of DNA corresponding to the genes for verotoxin, O157 and H7. The verotoxin genotype was VT2.

7.5 LIVESTOCK FARM ANIMAL FECAL SAMPLING

7.5.1 Methods
A review of topographical, soil, aerial and county maps was conducted to determine the flow of watercourses in the area surrounding Walkerton. Livestock farms were identified within a 4-km radius of the three wells that served the town. A minimum of five manure samples per farm were obtained and tested for human enteric pathogens at the CPHL. Sampling was conducted with the assistance of OMAFRA staff. During the visits, farmers were asked questions regarding type of livestock, herd size, manure handling practices, water drainage patterns, the effects of the heavy rains experienced in mid-May, recent farm well water quality, and whether an Environmental Farm Plan had been completed. On farms where manure specimens
positive for *E. coli* O157:H7 were identified, additional samples were obtained from cattle by rectal swab. All farms participated voluntarily and co-operated fully.

### 7.5.2 Results
A total of 13 livestock farms estimated to have some risk of run-off towards one or more of the municipal well sites were identified and visited between May 30 and June 13. Human bacterial pathogens were found in manure samples from 11 of the 13 farms. Specimens from two farms were positive for both *E. coli* O157:H7 and *Campylobacter jejuni*. One farm had a manure specimen that was positive for non-motile *E. coli* O157 and *C. coli*. Specimens positive for *C. jejuni* were found on seven farms, and specimens from one farm showed the presence of *C. coli*.

To confirm the initial results, follow-up testing was conducted on June 13 on the two farms where *E. coli* O157:H7 was identified, henceforth Farm 1 and Farm 2. On Farm 1, located in the vicinity of Wells 6 and 7, 20 of approximately 180 cattle were tested. Of the 20 animals, two were positive for *E. coli* O157:H7 and *C. jejuni*, two were positive for only *E. coli* O157:H7, seven were positive for *C. jejuni*, and one tested positive for *C. coli*. Nine animals were negative for any pathogens. All *E. coli* O157:H7 isolates had the phage type 14a and PFGE pattern A1. These findings were consistent with the subtyping results from *E. coli* O157:H7 isolates found on initial sampling. The *C. jejuni* isolates were phage types 2, 13, 19 var, 44 and 71. The *C. coli* isolate was phage type 2.

On Farm 2, located next to well 5, 38 of approximately 100 cattle were tested upon follow-up. Of the 38 cattle tested, six were positive for *E. coli* O157:H7, seven were positive for *C. jejuni*, and two were positive for *C. coli*. The phage type of all the *E. coli* O157:H7 isolates found on both visits were 14 and PFGE pattern A. The verotoxin genotype was VT2. Initial subtyping results from this farm also identified an *E. coli* O157 isolate with PFGE pattern A4. The phage type of all *C. jejuni* isolates was 33 and the majority of these isolates had a similar surface antigenic profile upon serotyping as seen in the human cases. Phage typing of one of the two *C. coli* isolates was 28, and the other *C. coli* isolate was not typed.

### 7.6 WILDLIFE FECAL SAMPLING

#### 7.6.1 Methods
With the assistance of a wildlife biologist from the Ministry of Natural Resources (MNR), the areas surrounding the three town wells were investigated for evidence of deer activity since deer are another potential source of *E. coli* O157:H7. This included checking trees for evidence of browse, and looking for deer tracks and droppings. Samples of suspected deer droppings were collected and submitted to the CPHL.

#### 7.6.2 Results
In the vicinity of Well 5, there was ample evidence of deer browse and tracks. One confirmed deer fecal sample and two possible deer fecal samples were collected. One
of the latter samples was positive for *A. hydrophila*, and the remaining two were negative for any human pathogens. In the vicinity of Wells 6 and 7, evidence of deer activity was also found. Two deer fecal samples collected in this area were both positive for *A. caviae*.

### 7.7 HYDROLOGICAL AND RAIN FALL SIMULATION MODEL

#### 7.7.1 Methods

The MNR provided the raw data used for creating the raindrop simulation. These data included a 10m-resolution digital elevation model (DEM) and infrared aerial photography with a 30cm spatial resolution. The analysis was performed using ArcView 3.2 GIS in conjunction with the extensions Spatial Analyst 1.1 and Hydrologic Modeling 1.1 from Environmental Systems Research Institute (ESRI). A hydrologic extension for ArcView 3.2 called Basins1, which was programmed by Ivan Petras of the Department of Water Affairs and Forestry (DWAF) in Pretoria, South Africa was also used.

To create the raindrop simulation, it was necessary to establish flow direction and flow accumulation from the DEM. This was done using the Hydrologic Modeling 1.1 extension from ESRI. Flow direction was established by assigning a numeric value to each cell to represent the direction that water flows. In this case, eight directions were used; North, South, East, West, Northeast, Northwest, Southeast and Southwest. The direction was assigned based on the greatest slope bordering each cell. Areas that did not have a direction value would not contribute to flow, but could receive flow. Therefore, very flat areas would be subject to a large amount of flow accumulation. Areas of high accumulation could be designated as streams based on a user-defined tolerance level.

The raindrop simulation was based on surface runoff, assuming water would always flow down the steepest available slope (unless a barrier was present). The direction and accumulation grids directed this flow based on surrounding cells. The raindrop simulation tool followed a hypothetical raindrop from a user-defined point through its watershed and eventually into a stream, river, lake and/or ocean.

In this particular case, a flow direction grid was created using the DEM provided by MNR. This flow direction grid was then used to create a flow accumulation grid. The hypothetical raindrops were placed directly on the cattle at the farm adjacent to Well 5, which were clearly visible on the aerial photograph. Using this it was possible to simulate the surface runoff.
7.7.2 Results
The simulation showed that rain falling in the vicinity of the barnyard where cattle have access, flowed south to the field west of Well 5, and then turned in direction toward Well 5 as seen in Figure 8. A graphic of a barn was placed in the area where cattle were visible in the photograph. A graphic of a well was placed in the treed area where Well 5 is located.

Figure 8: Modelled Farm Drainage
Walkerton, Ontario

The drainage path was created using a digital elevation model (DEM). It shows surface water run-off, assuming that water flows downward along the steepest slope available. The DEM has a 10 meter spatial resolution.
7.8 CONCLUSIONS

Results from tests of treated water in Well 5 taken in April and early May, 2000, indicated need for concern since coliform bacteria were found on three sampling dates. The results from the water samples taken on May 15, with tests completed on May 16, showed the water distribution system was already contaminated when the samples were taken. The results for treated Well 7 water added confusion as to whether Well 7 was the source of the problem.

Evidence was found in several past hydrogeological reports that Well 5 was subject to surface water infiltration, and that it was vulnerable to contamination from the agricultural activity located in close proximity to the well. Analysis of the water flow data confirmed that Wells 5 and 6 were supplying the town during the main exposure period of the cases. The timing of the heavy rainfall appears to have been a significant contributing factor as it also preceded the onset of illness of the cases. Well 7 was not running when the earliest cases were exposed. In addition, Well 7 was turned on the morning of May 15 and could not have been responsible for the contamination of the distribution system identified through water samples taken around the same time. These facts ruled out Well 7 as a possible source.

The PCR test results from Well 5 provided evidence that *E. coli* 0157:H7 had been present in the water. The verotoxin genotype (VT2) found in the water was also the same as the cases, which was a unique identifying feature of the clinical isolates. Both *E. coli* O157:H7 and *C. jejuni* of the same subtypes found in the patients were found in manure specimens on the farm next to Well 5. This confirmed the bacteria that entered the well were present in the immediate environment. Wildlife was not shown to be a reservoir for these pathogens. The model of rainfall suggested that run off could move toward the well from the farm, thus supporting the theory that bacteria originating on this farm could have entered the well.

Reference work conducted by the CPHL and the NLEP to further characterize the bacteria was critical to linking the pathogens found in patients’ stools to the environmental specimens.
8.0 SPATIAL AND TEMPORAL ANALYSIS

A model is being developed to quantify water flow patterns from the three wells during the outbreak period. It is anticipated that when analysed with case data, this information will help to confirm the well most likely responsible for the outbreak, together with the date and time of contamination. The results of this model are not yet available.
9.0 DISCUSSION AND FINAL CONCLUSIONS

The outbreak in Walkerton, Ontario in May and June, 2000 represented the largest, documented outbreak of waterborne, bacterial gastroenteritis due to multiple pathogens in Canada, and the first time *E. coli* O157:H7 has contaminated a municipal water supply in Canada. The impact of this event can not be overstated in terms of the burden of illness suffered including loss of life, and the prolonged disruption to the daily lives of the people of Walkerton. At the time of writing, the town’s water supply still lacked the safeguards needed to lift the Boil Water Advisory that has been in place since May 21.

A series of events occurred in May 2000 that led to the contamination of the Walkerton municipal water supply. These included unusually heavy rains accompanied by flooding, a shallow well subject to surface water contamination located in close proximity to a cattle farm, *E. coli* O157:H7 and *Campylobacter* spp. present in the adjacent cattle herd, and a water treatment system that likely was overwhelmed by turbid water. The seriousness of the clinical symptoms of infection with *E. coli* O157:H7 exhibited by the initial cases elicited prompt notification of the Medical Officer of Health.

The contaminated water supply was responsible for illness in as many as 1286 people in Walkerton, a town of 5000, representing 26% of the population. In addition, people living outside of Walkerton who were exposed to the water on a much more limited basis became ill, leading to an estimated total of over 2300 cases. This likely reflects both the low infectious dose of *E. coli* O157:H7 and *Campylobacter* spp. and the high degree of contamination of the water. The extra measures taken to control this outbreak, such as the use of chlorinated water for hand washing, added an enhanced level of protection beyond the Boil Water Advisory. These measures contributed to the mitigation of the outbreak and the prevention of many secondary cases.

Extensive efforts were made to determine the start date of the outbreak. This was important for evaluating which well(s) was involved and what circumstances contributed to the incident. The physician survey, which asked specifically about the time frame between May 8 to May 16, did not indicate an increase in doctors’ office visits for gastroenteritis during that time. It is possible that the timeframe evaluated by the physician survey was too narrow or that people seeking medical advice for diarrhea went directly to the emergency room. The emergency room in Walkerton reported seeing 7 people on May 19 with a 3 day history of diarrhea which developed into bloody diarrhea by May 19, suggesting that medical attention was not sought until symptoms were more severe. Follow-up of the accuracy of the reported dates of illness onset among three cases who became ill between mid-April and early May, were confirmed as accurate in two of the three cases. These cases had laboratory confirmation of infection with *E. coli* O157:H7 with the same phage type and PFGE pattern as the majority of cases, however, in each case the laboratory specimen was not submitted until later in May. This makes it difficult to determine if the *E. coli*
O157:H7 had been the initial cause of illness in the early cases or a result of subsequent exposure through the drinking water during the course of their illness. Based on this information it is impossible to determine the exact start of the outbreak, however, it is clear from the epidemic curve that the majority of cases were exposed after May 12 and continued to be exposed over a two week period.

The use of a cross-sectional study design to evaluate risk factors was beneficial as it also allowed for the determination of population-based rates of illness. The strong association between consumption of Walkerton municipal water and illness could be demonstrated at the household level and the individual level and was further supported by the dose response analysis. The spurious finding of meat consumption in the final model as a protective effect was unexpected. One possible explanation is that those who do not eat meat may eat more fruits and vegetables that would be washed before consumption, which could have led to increased opportunities for exposure. Another possible explanation would be that meat eaters have host factors that offer protection that non-meat eaters lack.

Inconsistencies between the well log data and the SCADA data could not be adequately explained despite great effort on the part of engineers and consultants evaluating the water flow equipment. The decision to rely on the SCADA data was made by consensus by investigators based on the fact that these data reflected a logical water use pattern for the town. Another piece of information that could not be explained adequately was the laboratory result from treated water at Well 7, analyzed on May 16. It would be very unusual for the raw water to have no E. coli or coliform bacteria, and the treated water to have in excess of 200 bacteria per 100 ml for both tests. The explanation for this finding remains unclear.

Efforts to determine the source well by mapping the distribution of cases in Walkerton by onset of illness did not show a particular pattern, although anecdotally people had the impression that illness began in the south end of town. It must be emphasized that location of residence does not necessarily indicate the location of exposure to a pathogen, thus the value of mapping the cases by residence to determine exposure site has limitations. It is unfortunate that the model of the water distribution system to quantify water flows by well is not yet complete. However, results of the modelling will be presented to the BGOSHU when they are available.

The finding of both E. coli O157:H7 and C. jejuni isolates of the same strain type as identified by molecular, phage and serotyping as the majority of the isolates from samples on the farm adjacent to Well 5, suggests the contamination originated from manure runoff from this farm. The samples from the farm were not taken until May 30, however, the best evidence suggests that heavy rains could have facilitated the movement of pathogens from the farm to the well, assuming the same bacteria were present in mid-May. The hydrological model described in this report helped to illustrate this theory which has been further explored by B.M. Ross and Associates Limited for the Municipality of Brockton using more sophisticated methods, and will be reported elsewhere. The fact that all but two of the livestock farms sampled had
human pathogens present, emphasizes the fact that these environmental risks are common and there is a need to protect both private and municipal wells from farm runoff. Since the farm in question was not a particularly large operation and followed an Environmental Farm Plan for manure handling, it is clear that protection of the groundwater must be addressed from multiple directions.

Before the Walkerton disaster, treated, deep, groundwater municipal water supplies were not considered to be a likely source of *E. coli* O157:H7. This outbreak calls into question the reliability of groundwater sources for drinking water especially when they are only subject to chlorination. Prevention of such outbreaks cannot rely on monitoring, testing and reporting since failures in the system can only be identified after the contaminating event. It is only through adequate well construction, appropriate watershed management and fail-safe water treatment methods that municipal water supplies can be properly protected. This outbreak also points out the difficulty of relying on hydrogeological studies of groundwater sources conducted during non-flooding conditions to properly evaluate the potential for surface water influence.

With increasing population density and changes in agriculture, the potential for the contamination of groundwater sources is increasingly a concern. This outbreak is a call to action to the regulators, water utility operators and public health community alike to ensure vigilance in ensuring the safety of our drinking water, a fundamental key to health.
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