						Scale of Outbreaks and Consequences				
Date	Location	Source Water	Treatment	Major Failures	Pathogens	Cases Confirmed	Total Cases Estimated	Hospital Admissions	Deaths	Comments
2000 Aug–2001 Nov	Asikkala, Finland	3 different groundwater systems	no chlorination	3 outbreaks in groundwater systems, all without chlorination, all due to *C. jejuni*	*Campylobacter jejuni*	A: 10; B: 5; C: 56	A ~400 B ~50 C ~1,000	not reported	–	Outbreaks A and C due to surface water contamination of wells following heavy rains, source of contamination of B was not determined.
2001 Mar–Apr	North Battleford, Saskatchewan, Canada	surface, river	coagulation, filtration, chlorination	poor fine-particle removal performance; intake located 3.5 km downstream of sewage effluent discharge	*Cryptosporidium parvum* type 1 (human)	375	5,800–7,100	50	–	Raw water quality problems caused by the sewage discharge were overlooked for years. In March 2001, maintenance to an upflow clarifier was followed by poor turbidity removal.
2001 May	Boarding school, Hawkes Bay, New Zealnd	surface, spring	pressure sand filter, cartridge filter, UV	cattle grazing in a swampy area where the springs arose, causing manure contamination of the raw water supply	*Campylobacter jejuni*	few stool samples taken	95–185	not reported	–	Although UV treatment was provided, the source water was allowed to become seriously contaminated and the treatment process was not operated effectively, UV lamp burned out.
2001 May–Jun	Camp, Stockholm County, Sweden	ground	no treatment	sewer system blocked and overflowed to contaminate shallow groundwater	Norwalk-like virus	8 of 11 samples	>200	not reported	–	This was a small scale outbreak because of the small number of people exposed but under the circumstances it is fortunate that a more severe pathogen was not involved.
2002 Feb–Mar	Transtrand, Sweden	ground	no treatment	cracked sewer located ~10 m from one well supplying the system responsible	Norwalk-like virus	4	~500	not reported	–	This outbreak was noteworthy because ~1/3 of cases could have been avoided by effective implementation of boil water advisory. The community opposed chemical disinfection and refused to believe waterborne transmission until the sewer damage was discovered.

4.2 WALKERTON, ONTARIO, CANADA

4.2.1 Scope of the Outbreak

Walkerton, Ontario, Canada is a moderately prosperous rural community (Figure 4.1) of 4,800 residents, located about 175 km northwest of Toronto. In May 2000, Walkerton experienced a disaster when its shallow groundwater supply was contaminated by bacterial pathogens in cattle manure from a local farm. In total, more than 2,300 individuals were estimated to have suffered gastrointestinal illness. Of these, 65 were hospitalized, 27 developed hemolytic uremic syndrome (HUS), a serious and potentially fatal kidney ailment, and 7 died.

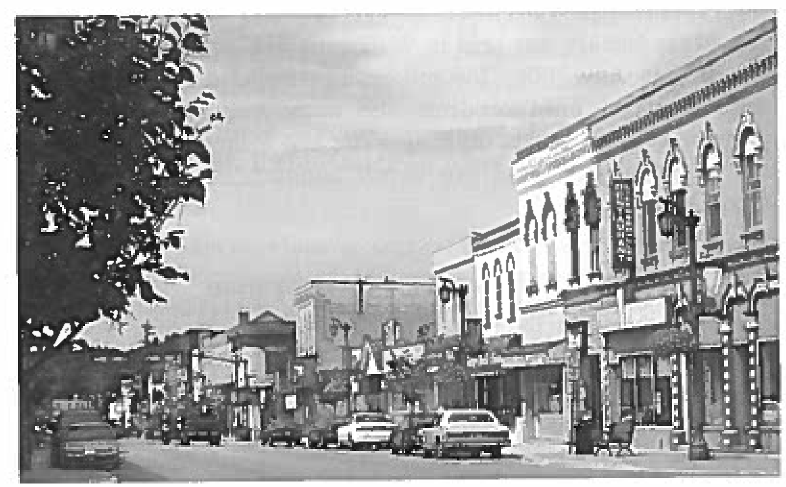

Figure 4.1 Durham Street, main street, Walkerton, Ontario (photo by S.E. Hrudey)

Escherichia coli O157:H7 and *Campylobacter jejuni* were the pathogens ultimately identified as being primarily responsible for these serious consequences, although other enteric pathogens may also have been present. The community was shocked that this tragedy happened in a province with a high standard of living, where citizens expected that their long-established regulatory and public health institutions would protect them against such a disaster. In such a small community, where everyone knew someone who was affected, the consequences were devastating. The trust residents had placed in

their local officials and the provincial government to assure the safety of their water supply was shattered. Walkerton became a Canadian icon for disastrous failure of public institutions.

The Government of Ontario called a public inquiry and appointed Justice Dennis R. O'Connor as Commissioner to determine what happened in Walkerton to cause this disaster, what role government policies, procedures and practices might have played and what steps may be necessary to ensure that Ontario drinking water would be safe in the future. The mandate was addressed in two parts by the Walkerton Inquiry.

The Part 1 report covered the events at Walkerton and the related government involvement (O'Connor, 2002a). The Part 2 report addressed the broader question of drinking water safety across Ontario (O'Connor, 2002b). Our discussion here will focus mainly upon the Part 1 report and evidence given at Part 1 of the Walkerton Inquiry (the Inquiry). The Part 2 report is discussed in Chapter 6, which deals with preventive measures identified following from the traumatic experience in Walkerton.

Part 1 of the Inquiry was held in Walkerton with evidence presented from October 2000 to July 2001. The proceedings included testimony from 114 witnesses, including town residents, the water treatment operators, water consultants, experts in health, drinking water and hydrogeology, various local officials, senior civil servants, two former ministers of environment and the Premier of Ontario.

4.2.2 The Walkerton Drinking Water System

Walkerton was served by three wells in May of 2000, identified as Wells 5, 6 and 7. Well 5 was located on the southwest edge of the town, bordering adjacent farm land. It was drilled in 1978 to a depth of 15 m with 2.5 m of overburden and protective casing pipe to 5 m depth (O'Connor, 2002a; Ross, 2000). The well was completed in fractured limestone with the water-producing zones ranging from 5.5 to 7.4 m depth and it provided a capacity of 1.8 ML/d that was able to deliver ~56% of the community water demand. Well 5 water was to be chlorinated with hypochlorite solution.

Well 6 was located 3 km west of Walkerton in rural countryside and was drilled in 1982 to a depth of 72 m with 6.1 m of overburden and protective casing to 12.5 m depth (O'Connor, 2002a; Ross, 2000). An assessment after the outbreak determined that Well 6 operated from seven producing zones with approximately half the water coming from a depth of 19.2 m. This supply was judged to be hydraulically connected to surface water in an adjacent wetland and a nearby private pond (MOE, 2000). Well 6 was disinfected by a gas chlorinator

and provided a nominal capacity of 1.5 ML/d that was able to deliver 42 to 52% of the community water demand (Ross, 2000; O'Connor, 2002a).

Well 7, located approximately 300 m northwest of Well 6, was drilled in 1987 to a depth of 76.2 m with 6.1 m of overburden and protective casing to 13.7 m depth (Ross, 2000; O'Connor, 2002a). An assessment following the outbreak determined that Well 7 operated from three producing zones at depths greater than 45 m with half the water produced from below 72 m. A hydraulic connection discovered between Well 6 and Well 7 reduced the security of an otherwise good-quality groundwater supply (MOE, 2000). Well 7 was also disinfected by a gas chlorinator and provided a nominal capacity of 4.4 ML/d that was able to deliver 125 to 140% of the community water demand (Ross, 2000; O'Connor, 2002a).

Ironically, Well 5 was drilled to provide softer water than Walkerton was able to acquire from its deeper and more secure groundwater sources. Well 5 was seen initially as a "stop gap" to acquire a soft water supply at low cost (S. Koebel, W.I. Transcript, Dec. 18, 2000, p. 35). Unfortunately, as events were about to show, water from Well 5 was softer because it had been rainwater much more recently than water from the deeper aquifers.

4.2.3 The Outbreak Experience in May 2000

4.2.3.1 Introduction

The following account is primarily derived from the Part 1 Inquiry Report (O'Connor 2002a), supplemented by testimony and documentary evidence presented at the Inquiry. Obviously, much more information on these events is documented in the Inquiry report. The reader interested in greater detail about the roles played and contributions made by the various individuals involved is encouraged to refer to the Inquiry report, which is very readable and extremely informative about the dynamics of this far-reaching failure. A more personal documentary account of this tragedy (Perkel, 2002) is also recommended reading. The key players involved are summarized in Box 4.1.

4.2.3.2 May 8, 2000 – Heavy Rainfall and Local Flooding

From May 8 to May 12, Walkerton experienced an accumulation of approximately 134 mm of rainfall, with 70 mm falling on the last day. This was unusually heavy, but not record, precipitation. Such rainfall over a 5-day period was estimated by Environment Canada to happen approximately once in 60 years (on average) for this region in May. The rainfall of May 12, which was estimated by hydraulic modeling to have occurred mainly between 6 PM and midnight, produced flooding in the Walkerton area.

Box 4.1 Key players in the course of the Walkerton outbreak

Name	Position	Employer
Allen Buckle	Employee	Walkerton Public Utilities Commission
Phillip Bye	District Supervisor	Owen Sound and District Office Ontario Ministry of Environment
John Earl	Environmental Officer	Owen Sound and District Office Ontario Ministry of Environment
Dr. Kristen Hallett	Pediatrician	Owen Sound
Stan Koebel	General Manager	Walkerton Public Utilities Commission
Frank Koebel	Foreman	Walkerton Public Utilities Commission
Robert MacKay	Employee	Walkerton Public Utilities Commission
Dr. Murray McQuigge	Medical Officer of Health	Bruce-Grey-Owen Sound Health Unit
David Patterson	Assistant Director Health Protection	Bruce-Grey-Owen Sound Health Unit
James Schmidt	Public Health Inspector	Bruce-Grey-Owen Sound Health Unit
David Thomson	Mayor	Municipality of Brockton (includes Walkerton)
Michelle Zillinger	Environmental Officer	Owen Sound and District Office Ontario Ministry of Environment

Stan Koebel, the general manager of the Walkerton Public Utilities Commission (PUC), was responsible for managing the overall operation of the drinking water supply and the electrical power utility. From May 5 to May 14, he was away from Walkerton, in part to attend an Ontario Water Works Association meeting. He had left instructions with his brother Frank, the foreman for the Walkerton PUC, to replace a non-functioning chlorinator on Well 7. From May 3 to May 9, Well 7 was providing the town with unchlorinated water in contravention of the applicable provincial water treatment requirements, the Ontario Drinking Water Objectives (ODWO) and Bulletin 65-W-4 on Chlorination of Potable Water Supplies (the Chlorination Bulletin).

From May 9 to 15, the water supply was switched to Wells 5 and 6. Well 5 was the primary source during this period, with Well 6 cycling on and off, except for a period from 10:45 PM on May 12 until 2:15 PM on May 13 when Well 5 was shut down. Testimony at the Inquiry offered no direct explanation about this temporary shutdown of Well 5. No one admitted to turning Well 5 off and the supervisory control and data acquisition (SCADA) system was set to keep Well 5 pumping. Flooding was observed near Well 5 on the evening of May 12 because of the heavy rainfall that night, but why or how Well 5 was shut down for this period remains unknown.

On May 13 at 2:15 PM, Well 5 resumed pumping. That afternoon, according to the daily operating sheets, foreman Frank Koebel performed the routine daily checks on pumping flow rates and chlorine usage, and measured the chlorine residual on the water entering the distribution system. He recorded a daily chlorine residual measurement of 0.75 mg/L for Well 5 treated water on May 13 and again for May 14 and 15. The Inquiry concluded that these chlorine residual measurements were never made and that the operating sheet entries were fictitious.

On Monday, May 15, Stan Koebel returned and early in the morning turned on Well 7, presumably believing that his instruction to install the new chlorinator had been followed. When he learned a few hours later that it had not, he continued to allow Well 7 to pump into the Walkerton system, without chlorination, until Saturday, May 20. Well 5 was shut off at 1:15 PM on May 15, making the unchlorinated Well 7 supply the only source of water for Walkerton.

PUC employees routinely collected water samples for bacteriological testing on Mondays. Samples of raw and treated water were to be collected at Well 7 that day along with two samples from the distribution system. Although samples labeled *Well 7 raw* and *Well 7 treated* were submitted for bacteriological analyses, the Inquiry concluded that these samples were not taken at Well 7 and were more likely to be representative of Well 5. Stan Koebel testified that PUC employees, including Allen Buckle, who sampled in this case, sometimes collected their samples at the PUC shop, located nearby and immediately downstream from Well 5, rather than traveling to the more distant wells (~ 3km away) or distribution system sample locations. The reason for these failings provided by Stan Koebel at the Inquiry was "*Simply convenience, or just couldn't be bothered.*" (S. Koebel, W.I. Transcript, Dec. 19, 2000, p. 170).

During this period, a new water main was being installed (the Highway 9 project). The contractor and consultant for this project asked Stan Koebel if they could submit their water samples from this project to the laboratory being used by the Walkerton PUC for bacteriological testing. Stan Koebel agreed and included three samples from two hydrants for the Highway 9 project. On May 1, the PUC began using a new laboratory for bacteriological testing, a lab the PUC had previously used only for chemical analyses. The PUC's previous microbiology lab had advised the PUC that it would no longer accept water samples for routine bacteriological testing.

The first set of samples submitted to the new laboratory was taken on May 1, but was improperly submitted with inadequate sample volumes for the analyses requested and discrepancies between the written documentation and numbers of samples sent. No samples were submitted by the PUC for May 8. The May 15

PUC samples repeated the problems with inadequate sample volumes and discrepancies in the paperwork.

4.2.3.3 May 17 – Laboratory Report to PUC of E. coli Contamination

The results of the samples collected on May 1 were reported on May 5 and indicated that both raw and treated water at Well 5 were positive for total coliforms. Early on the morning of Wednesday, May 17, the lab phoned Stan Koebel to advise him that all of the water main construction project samples were positive for *E. coli* and total coliforms, and that the distribution system samples were also contaminated. Because these tests indicated only the presence or absence of indicator bacteria, it was not possible to estimate the numbers of indicator bacteria in each sample. Only the sample labeled *Well 7 treated* was analyzed by the membrane filtration method. The latter procedure would normally allow a bacterial count to be determined, but in this case the sample was so contaminated that it produced an overgrown plate with bacterial colonies too numerous to count (both total coliforms and *E. coli* > 200 / 100 mL). As noted above, the Inquiry concluded that this sample was most likely mislabeled and was more likely representative of the water from Well 5 entering the distribution system.

The new laboratory was not familiar with the expectations outlined in the ODWO to report adverse microbial results to either the Ministry of Environment (MOE) or the responsible Medical Officer of Health (MOH). Accordingly, this lab reported these adverse sample results only to Stan Koebel. In turn, he advised the consultant for the Highway 9 project contractor that their samples had failed so they would need to re-chlorinate, flush and re-sample to complete the project.

4.2.3.4 May 18 – First Cases of Illness Recognized

On Thursday, May 18, the first signs of illness were becoming evident in the healthcare system. Two children, a seven-year-old and a nine-year-old, were admitted to the hospital in Owen Sound, 65 km from Walkerton. The first child had bloody diarrhea and the second developed bloody diarrhea that evening. The attending pediatrician, Dr. Kristen Hallett, noted that both children were from Walkerton and attended the Mother Theresa school. Bloody diarrhea is a notable symptom for serious gastrointestinal infection, particularly infection with *E. coli* O157:H7. Accordingly, Dr. Hallett submitted stool samples from these children to evaluate that diagnosis. By May 18, at least 20 students were absent from the Mother Theresa school.

By Friday, May 19, the outbreak was evident at many levels. Twenty-five children were now absent from the Mother Theresa school and 8 children from the Walkerton public school were sent home suffering from stomach pain,

diarrhea and nausea. Three residents of the Maple Court Villa retirement home and several residents of the Brucelea Haven long-term care facility developed diarrhea, two with bloody diarrhea. A Walkerton physician had examined 12 or 13 patients suffering from diarrhea. Dr. Hallett first notified the Bruce-Grey-Owen Sound Health Unit (BGOSHU), the responsible public health agency for Walkerton with its main office in Owen Sound, of the emerging problems on May 19. She expressed concerns to Health Unit staff that Walkerton residents were telling her something was "*going on*" in Walkerton, and the receptionist from the Mother Theresa school advised that the parent of one student stated that something was wrong with the town's water supply.

An administrator at the Mother Theresa school called James Schmidt, the public health inspector at the Walkerton office of the Health Unit, to report the 25 children absent. She noted that some were from Walkerton, others from adjacent rural areas, and that the ill students were from different grades and classrooms. She suspected the town's water supply. In contrast, the Health Unit officials suspected a food-borne basis for the outbreak, by far the most common cause of such diseases. Nonetheless, James Schmidt placed a call to Stan Koebel in the early afternoon. By the time he called, the chlorinator had been installed on Well 7 so that it was supplying chlorinated water to Walkerton's distribution system. According to James Schmidt, he asked whether anything was wrong with Walkerton's water and Stan Koebel advised him that "*everything's okay*" (J. Schmidt, W.I. Transcript, Dec. 15, 2000, p. 172). By then, Stan Koebel had been faxed the adverse microbial results from the Highway 9 project, the distribution system and the sample labeled *Well 7 treated* two days earlier.

Later that afternoon, David Patterson, an administrator of the Health Unit based in Owen Sound, called Stan Koebel to advise him of public concerns about the water. Patterson asked whether anything unusual had happened in the water system. Stan Koebel mentioned that there was water main construction underway near the Mother Theresa school, but made no mention of the adverse bacteriological results or of operating Well 7 from May 3 to 9 and from May 15 to 19 without a chlorinator.

The Inquiry concluded that Stan Koebel's lack of candour seriously hampered the Health Unit's early investigation of and response to the outbreak. Because patients had bloody diarrhea, health officials suspected the outbreak was caused by *E. coli* O157:H7, but this pathogen is most commonly associated with food-borne outbreaks. At that time, Health Unit personnel were not aware that any outbreaks of this disease had occurred in a treated drinking water system. (The best known waterborne outbreaks of *E. coli* O157:H7 that are described later in this chapter — Cabool, Missouri; Alpine, Wyoming; and Washington County, New York — involved unchlorinated drinking water). Stan Koebel's reassurances about the water safety kept the Health Unit staff pursuing

a food-borne cause. However, the emerging outbreak, with cases distributed across a wide geographic region and across the very young and very old, was progressively making any food-borne explanation increasingly improbable.

Suspicions about the safety of the water were spreading in the community. The Brucelea Haven nursing home, where a number of patients had become ill, began to boil water. Some citizens, including Robert MacKay, an employee of the Walkerton PUC, also began to boil their water on Friday, May 19. After his conversations with health officials that afternoon, in which he reassured them about the water, Stan Koebel increased the chlorination level at Well 7. He also began to flush the distribution system through a hydrant near the Mother Theresa school and subsequently at other hydrants throughout the system until May 22.

By Saturday, May 20, on a holiday long weekend, the outbreak was straining the Walkerton hospital with more than 120 calls from concerned residents, more than half of whom complained of bloody diarrhea. After the Owen Sound hospital determined that a stool sample from one of the children admitted on May 18 was presumptive positive for *E. coli* O157:H7, the health unit notified other hospitals in the region because this pathogen may cause hemolytic uremic syndrome (HUS). This warning was important because anti-diarrheal medication or antibiotics can worsen the condition of patients infected with this pathogen, so emergency staff had to be aware not to dispense such medication.

David Patterson asked James Schmidt to contact Stan Koebel again to determine the current chlorine residual levels in the water and to receive reassurance that the water system would be monitored over the holiday weekend. Koebel assured Schmidt that there were measurable levels of chlorine residual in the distribution system, leading health officials to believe that the water system was secure.

Early on Saturday afternoon, David Patterson contacted Dr. Murray McQuigge, the local Medical Officer of Health who was out of town during the onset of the outbreak, to advise him of the emerging outbreak. By that time, several people in Walkerton were reporting bloody diarrhea and ten stool samples had been submitted for pathogen confirmation. Dr. McQuigge advised that any further cases diagnosed with *E. coli* O157:H7 should be interviewed for more details, and he returned that evening to Owen Sound.

David Patterson called Stan Koebel to advise him that a local radio station was reporting that Walkerton water should not be consumed. Patterson wanted Koebel to call the radio station to correct this report and reassure the public about the safety of the Walkerton water supply, but Koebel was apparently reluctant to comply with this request. Patterson asked again whether anything unusual had occurred in the water system and Koebel again failed to report the

adverse results from the May 15 samples or that Well 7 had been operating with no chlorination.

Robert MacKay, who had been on sick leave from the PUC, began to suspect something was wrong with Walkerton's water. He had learned from Frank Koebel that the samples from the Highway 9 project had failed testing. MacKay phoned the Spills Action Centre (SAC) of the MOE anonymously to report his concerns and provide a contact number at the PUC for the MOE to call about the Walkerton water system. In the early afternoon of Saturday, May 20, Christopher Johnston, the MOE employee who received MacKay's anonymous call, phoned Stan Koebel to find out if there were problems with the system. Johnston understood from this conversation with Stan Koebel that any problems with bacteriological results had been limited to the Highway 9 mains replacement project some weeks earlier, but that chlorine residual levels were satisfactory as of May 19. MacKay, now experiencing diarrhea himself, placed another call to the MOE number that evening to find out what was being done. MacKay was advised that Stan Koebel had been contacted, but that MacKay's concern about drinking water safety was really a matter for the Ministry of Health. This feedback from the MOE was wrong: the MOE was designated as the lead agency for drinking water regulation in Ontario. MacKay was provided with a phone number for the wrong regional health office, eventually leading him to call back to the SAC. This time, the MOE SAC staff person agreed to contact the nearest MOE office, in Owen Sound, with a request to look into the matter.

4.2.3.5 May 21 – Boil Water Advisory Issued by Health Unit

The outbreak continued to expand. By Sunday, May 21, there were more than 140 calls to the Walkerton hospital and two more patients admitted to the Owen Sound hospital. A local radio station interviewed Dr. McQuigge on Sunday morning and subsequently reported on the noon news that Dr. McQuigge believed that drinking water contamination was an unlikely source of this outbreak. At about that time, the Health Unit was advised that the first presumptive *E. coli* O157:H7 had been confirmed and that another patient sample, presumptive for *E. coli* O157:H7, was being tested for confirmation. David Patterson and Dr. McQuigge conferred with their staff about these results and decided to issue a boil water advisory at 1:30 PM on Sunday, May 21. The notice, hastily drafted by David Patterson, read as follows:

> The Bruce-Grey-Owen Sound Health Unit is advising residents in the Town of Walkerton to boil their drinking water or use bottled water until further notice. The water should be boiled for five minutes prior to consumption. This recommendation is being made due to a significant increase in cases of diarrhea in this community over the past several days.

> Although the Walkerton PUC is not aware of any problems with their water system, this advisory is being issued by the Bruce-Grey-Owen Sound Health Unit as a precaution until more information is known about the illness and the status of the water supply.
>
> Anybody with bloody diarrhea should contact his or her doctor or the local hospital.

This notice was provided only to the local AM and FM radio stations; additional publicity by the television station or by direct door-to-door notification was not pursued. According to the report subsequently prepared on the outbreak with the assistance of Health Canada (BGOSHU, 2000), a community survey showed that only 44% of respondents were aware that the Health Unit had issued a boil water advisory on May 21 and only 34% heard the announcement on the radio. In retrospect, Health Unit personnel acknowledged that the community could have been more effectively notified. However, given Stan Koebel's consistent reassurance about the safety of the Walkerton water system, the Health Unit's caution in attributing the outbreak to the local drinking water at this emerging stage of the outbreak is understandable.

After issuing the boil water advisory, Dr. McQuigge notified the MOE SAC that there was an *E. coli* outbreak in Walkerton. In exchange, the SAC advised Dr. McQuigge about the anonymous calls about adverse results for the Walkerton water system. The Health Unit updated the MOE SAC that there were now 2 confirmed cases of *E. coli* O157:H7 and 50 cases of bloody diarrhea. The MOE called Stan Koebel to discuss the situation; Koebel again failed to report the adverse samples from May 15 (reported to him on May 17). During his Inquiry testimony, Stan Koebel responded to a question about whether he had deliberately avoided disclosing these results during his conversation with Ministry of the Environment personnel by answering: "*I guess that's basically the truth and I was waiting on the Ministry of the Environment to call from the Owen Sound office with further confirmation*" (S. Koebel, W.I. Transcript, December 20, 2000, p. 108).

The Health Unit established a strategic outbreak team to deal with the emergency. Local public institutions were to be notified about the boil water advisory, but the Brucelea Haven nursing home and the Maple Court Villa retirement home were inadvertently missed. The Walkerton hospital had been reassured about the safety of the water until that afternoon and had not taken any measures to address water safety. In fact, hospital staff had been advising those caring for diarrhea patients to provide ample fluids to maintain patient hydration, advice that caused many ill patients to receive more exposure to contaminated water.

Once notified of the problems, the hospital was forced to find an alternative safe water and ice supply, shut off its public fountains, and discard any food

prepared or washed with Walkerton tap water. By that evening, the Health Unit had notified provincial health officials of the outbreak and requested the assistance of major hospitals in London and Toronto in treating Walkerton residents and the assistance of Health Canada in conducting an epidemiological investigation.

By Monday, May 22, the Health Unit had received reports of 90 to 100 cases of *E. coli* infection. Phillip Bye, the regional MOE official in Owen Sound, who had been notified the previous evening about the outbreak, did not initiate a MOE investigation, even after being advised about the large number of cases of *E. coli* infection and that the Health Unit suspected the Walkerton water system. Only after being contacted later that day by Dr. McQuigge, who stressed the urgency of the situation, did the regional MOE initiate an investigation by sending environmental officer James Earl to Walkerton to meet first with the Health Unit before meeting Stan Koebel. The Health Unit advised Earl about the "*alarming*" number of illnesses and said that Health Unit investigations failed to reveal any plausible food-borne cause, making the water system highly suspect. David Patterson asked Earl to obtain any microbiological test results from the PUC for the previous two weeks. Earl was also informed of the anonymous call, and he surmised that intentional contamination might be possible. When Earl interviewed Stan Koebel and asked about any unusual events of the previous two weeks, Koebel did not tell him about the adverse bacteriological results for May 15 or the operation of Well 7 without a chlorinator. However, Koebel provided Earl with a number of documents, including the May 17 report (results for May 15). Stan Koebel told him that the daily operating sheet for Well 7 was not available, but that Earl could pick it up the next day.

James Earl returned to Owen Sound and reviewed these documents that evening. Although Earl noted the result showing high *E. coli* numbers for the water system, he did not report this alarming evidence to his supervisor, Phillip Bye or the Health Unit at that time. James Earl apparently believed that the boil water advisory eliminated any urgency concerning the revelation about adverse microbial results for Walkerton's drinking water supply.

In the meantime, the Health Unit began to plot an epidemic curve that revealed an apparent peak of disease onset for May 17, suggesting a likely date of contamination between May 12 and 14. They also plotted the residence locations for those who were infected. This plot revealed that cases were distributed all across the area served by the Walkerton distribution system. By that evening, the Health Unit was convinced this was a waterborne outbreak, even though they had not yet been provided with the adverse results for May 15. On May 22, the first victim of the outbreak, a 66-year-old woman, died.

4.2.3.6 May 23 – Health Unit Learns of E. coli Contamination Results

James Earl returned to Stan Koebel on the morning of Tuesday, May 23, to pick up the remaining documents for Well 7 and to collect samples from the wells. The Well 7 daily operating sheet that Stan Koebel provided had been altered by Frank Koebel on May 22 or 23, on Stan's instructions to "*clean up*" the daily operating summary sheet for May. The Inquiry concluded that this had been done to conceal the reality of Well 7 operating without chlorination. Numbers were entered for chlorine used in the previous 24 hours and for chlorine residuals on days when no chlorination was performed. Frank Koebel testified at the Inquiry to composing these numbers "*so it would look better to the MOE*."

That morning, the Health Unit received results of bacteriological analyses from samples it had collected around Walkerton. Two samples, from dead end locations, showed *E. coli* and total coliforms while a second set of samples submitted showed signs of coliforms. When David Patterson called Stan Koebel to advise him of these results, he asked the date of the last bacteriological tests for the PUC. For the first time, Stan Koebel admitted the adverse May 17 report and expressed distress upon realizing that his attempts to fix the problem had failed. Koebel asked Patterson for advice and was told to be open and honest and to inform the PUC commissioners about what happened. Patterson immediately informed Dr. McQuigge, who in turn called a meeting with Mayor David Thomson and the local council for the municipality of Brockton, which included the Town of Walkerton.

Prior to this meeting, Dr. McQuigge held a news conference to report on the seriousness of the outbreak, with eleven people admitted to hospital and three in serious condition. He indicated that there was a 7% risk of renal failure, the death rate could be 1 to 3%, and antibiotics and diarrhea medications should not be used because they increased the risk of HUS. Dr. McQuigge advised that the Health Unit had confirmed contaminated water samples, and he suggested that exposure to the contamination likely occurred between May 12 and 14.

At the Brockton council, Dr. McQuigge explained why the Health Unit personnel were convinced that water was responsible and confirmed the severity of the illness occurring in the community, with nine patients having confirmed infections with *E. coli* O157:H7 and a two-year-old currently on life support. Before the end of that day, the infant died.

Phillip Bye advised the meeting about possible explanations for the contamination. He indicated that the MOE was initiating an investigation, that the PUC should undertake its own investigation and that an independent agency should take over the operation of the water system.

Dr. McQuigge asked Stan Koebel whether he had anything to contribute to this discussion. When Koebel discussed a range of circumstances without making any reference to the May 15 adverse bacteriological samples or operating Well 7 without a chlorinator, Dr. McQuigge challenged him to "*come clean.*" Following some pointed questions, Koebel admitted the adverse bacteriological results, but not the operation of Well 7 without a chlorinator.

Some council members responded by questioning Dr. McQuigge about the timeliness of the boil water advisory. Sharp words were exchanged between Mayor Thomson and Dr. McQuigge at the end of this meeting. The Inquiry heard divergent accounts about what was said between these two. The Health Unit and the Town of Walkerton saw the causes of this emerging disaster quite differently. Later that afternoon, the council and administration met with the town's engineering consultant to develop an action plan to satisfy the MOE. The consultant advised that continued chlorination and flushing of the system should be pursued, and Well 5 was shut down because it was a vulnerable shallow well.

During the last week of May, local medical staff struggled to cope with the outbreak, continuing to see double or more the number of patients that they would normally see daily in the emergency room. By May 24, the fatality count reached four and a number of patients had to be transported by air ambulance to London, Ontario (170 km away) for medical care.

The Ontario Clean Water Agency took over the operation of the water system, continuing to flush and chlorinate, and ultimately bringing in a transportable water treatment plant. The boil water advisory of May 21 was not lifted until December 5, 2000, more than six months after the contamination occurred.

Box 4.2 Timeline of major events in Walkerton for May 2000

Date in May	Activities	Source
8th Monday	•Start of heavy rainfall	
9th Tuesday		•Well 5 primary source •Well 6 cycled on and off •Well 7 shut off
10th Wednesday	•134 mm of rain fell over 5 days (~ 1 in 60 year occurrence for this region in May)	
11th Thursday		
12th Friday	•Heaviest day of rain, 70 mm	
13th Saturday	•Frank Koebel checked Well 5 but did not measure chlorine residual	
14th Sunday	•Frank Koebel checked Well 5 but did not measure chlorine residual	
15th Monday	•An unidentified PUC employee checked Well 5 but did not measure chlorine residual •Allen Buckle collected 3 samples (likely mislabeled and likely taken downstream from Well 5) for bacteriological analysis •Stan Koebel took 1 sample from distribution system and received 3 samples from Highway 9 mains construction site •Samples sent to new laboratory for analysis	•Well 7 turned on without chlorinator at 6:15AM •Well 5 shut off at 1:15PM
16th Tuesday	•Samples received by the new laboratory and prepared for analysis •The supervisor at the new laboratory called Stan Koebel to advise that samples were submitted incorrectly again	
17th Wednesday	•New laboratory supervisor called Stan Koebel to advise him that construction site samples were positive for *E. coli* and the Walkerton samples "*didn't look good either*" •New laboratory faxed these failing results to Stan Koebel •New laboratory did not send results to the Ontario MOE because it was not aware of the conventional (but not mandated) practice	
18th Thursday	•Two children admitted to Owen Sound Hospital with bloody diarrhea •Growing absenteeism in Walkerton schools •Public called the PUC inquiring about water safety but were assured that everything was "*okay*"	
19th Friday	• Greater absenteeism in schools • Illness at local retirement home and long-term care facility •Dr. Hallet contacted local Health Unit over concern that children with bloody diarrhea were suffering from *E. coli* infection •Local Health Unit began investigation, including speaking with Stan Koebel. He assured them that the water was "*okay*" •Stan Koebel began to flush and superchlorinate the system and continued to do so over the weekend	By noon the chlorinator was finally installed and operational on Well 7
20th Saturday	•A holiday long weekend •One stool sample from child at the Owen Sound Hospital tested presumptive positive for *E. coli* O157:H7 •Health Unit staff spoke twice with Stan Koebel and were reassured that the water showed chlorine residuals and was okay •Health Unit relied on information from Stan Koebel to reassure public callers •Robert MacKay, a PUC employee, placed an anonymous call to the MOE Spills Action Centre (SAC) to advise about the failed construction site samples •SAC staff person called Koebel and came away understanding that only the construction site samples were bad •Local Health Unit called Dr. McQuigge, the Medical Officer of Health	Well 7 continued operation with the chlorinator functional
21st Sunday	•The Owen Sound hospital confirmed the presumptive test for *E. coli* O157:H7 and confirmed another presumptive result •The Health Unit announced a boil water advisory at 1 p.m. •Dr. McQuigge called the Mayor of Brockton to advise him of the boil water advisory •The Walkerton Hospital had more than 270 calls concerning gastrointestinal illness •A child was air-lifted from Walkerton to a London, Ontario hospital	Well 7 continued Operation
22nd Monday	•The MOE began investigating the Walkerton water system •Stan Koebel only told the MOE that Well 6 had been knocked out by the electrical storm on the weekend of May 13, but he did not mention the operation of Well 7 without a chlorinator or the adverse bacteriological results for May 15 •In response to a request for documents, he provided the May 17 fax from the lab, with the May 15 adverse results and the operating logs for Wells 5 & 6 •Stan Koebel instructed Frank Koebel to clean up the operating log for Well 7 •The first victim died	
23rd Tuesday	•Stan Koebel provided the MOE with the altered log for Well 7 •Two of the samples collected by the Health Unit reported positive for *E. coli* •When advised of these results, Stan Koebel told the Health Unit about the May 15 results •A meeting was held between the Brockton council, the PUC, the MOE and Health Unit personnel •Stan Koebel was confronted by Health Unit personnel when he did not volunteer his knowledge about what he had known to the others present •The second victim died	
24th Wednesday	•Some patients developed mixed infections of *C. jejuni* and *E. coli* O157:H7 •Several patients had been transferred to London •Health Canada epidemiologists arrived to work with the Health Unit on epidemiological investigations •Two more victims died	

25th Thursday	•Dr. McQuigge gave media interviews to explain the actions of the Health Unit and that information had been withheld from them •Brockton retained the Ontario Clean Water Agency to operate the Walkerton water system	
26th Friday	•A microbiologist from the lab which had done Walkerton testing until the end of April 2000 advised in a media interview that Walkerton had experienced 5 incidents with coliforms between January and the end of April 2000 (four in April) and that these had been reported to the Owen Sound office of the MOE. One of these results was deemed an indication of "*unsafe*" water and should have been reported to the local Health Unit, but was not	
27th Saturday	•MOE officials met with Health Unit and confirmed that they had failed to discharge their responsibility under the Ontario Drinking Water Objectives to notify the Health Unit about adverse bacteriological results on April 10, 2000	

4.2.4 Direct Causes of the Walkerton Outbreak

The chronology of the outbreak in Walkerton is informative because it illustrates the emerging and often confusing patterns of evidence suggesting several possible causes. These patterns show the difficulty of reaching conclusions because of bias and the slow rate that partial evidence emerges. As the outbreak progressed, the passage of time impaired the ability to collect sufficient evidence to test all theories. Despite the dedication of considerable resources to the investigation of this outbreak, a number of relevant details remain unresolved or unclear. The inability to turn back the clock and collect samples at key points will always be a constraint on our full understanding of the direct causes of any outbreak.

There were many potential direct causes for this outbreak, including new water main construction, fire events, main breaks and repairs, contamination of treated water storage, cross connections, flooding and human sewage or sewage sludge contamination of the wells. Despite the diversity of possible causes, the Inquiry found consistent and convincing evidence that this outbreak was caused by contamination from cattle manure being washed from an adjacent farm into the shallow Well 5 on or about May 12 because of the heavy rainfall that day. Consequently, the following explanations will focus on the evidence for and understanding of that specific cause. Other plausible causes will be mentioned only briefly. However, under different circumstances, each of these could have caused or contributed to an outbreak.

Well 5 (Figure 4.2) was identified as being vulnerable to surface contamination from the time it was first commissioned. The hydrogeologist who conducted the original assessment of this well wrote in his commissioning report:

> The results of the bacteriological examination indicate pollution from human or animal sources, however, this was not confirmed by the chemical analyses. The supply should definitely be chlorinated and the bacteria content of the raw and treated water supply should be monitored. The nitrate content should also be observed on a regular basis...
>
> The Town of Walkerton should consider establishing a water-protection area by acquiring additional property to the west and south in the vicinity of Well four [now 5]. Shallow aquifers are prone to pollution in farming and human activities should be kept away from the site of the new well as far as possible...
>
> (Wilson (1978) reported in Nov 8, 2000 W.I. Transcript; evidence of J. Budziakowski).

Pump testing on this well in 1978 demonstrated that bacteriological contamination occurred within 12 to 24 hours of initiating pumping, reaching a peak of 12 fecal coliforms per 100 mL after 48 hours.

During the well's first two years, the MOE conducted a number of inspections that revealed continuing concerns for surface contamination. These concerns included the nearby agricultural activities; the shallowness of the well with its relatively thin overburden; observed fluctuations in turbidity; bacteriological monitoring indicating fecal contamination; and elevated pumping levels in concert with spring thaw and early rainfall suggesting rapid surface recharge of the shallow aquifer. In 1980, the bacteriological samples of the raw water at Well 5 reached as high as 260 total coliforms per 100 mL and 230 fecal coliforms per 100 mL, with 4 out of 42 samples that year showing bacterial contamination. Because none of the chlorine disinfected samples from Well 5 showed bacterial contamination, the poorer quality raw water seems to have been accepted despite the obvious signs of surface contamination. Turbidity measurements were found to be occasionally elevated (up to 3.5 NTU) and to fluctuate well beyond what would be expected from a secure groundwater source.

Unfortunately, the concerns about surface contamination influencing the raw water at Well 5 appeared to have been forgotten in the MOE files during the 1980s when no inspections were performed. However, the investigation by Golder Associates Ltd. (Golder, 2000) after the outbreak confirmed that Well 5 was definitely under the influence of surface contamination, as the early water quality monitoring indicators had so clearly revealed. In a dramatic demonstration, a shallow pond (~10 cm deep) adjacent to Well 5 went dry within 30 minutes after the pump test commenced, and a deeper nearby pond dropped 27 cm over 36 hours of pumping. Furthermore, subsequent tracer tests conclusively demonstrated the hydraulic connection between the surface pond and the producing zone of Well 5. In fact, there were multiple entry points to the

shallow aquifer feeding Well 5, possibly including point source breaches of the overburden by fencepost holes, improperly abandoned wells (none were located) and sand or gravel lenses. The investigations after the outbreak did not confirm the exact route of contamination entry into Well 5, but the relevant experts at the Inquiry agreed that the overall evidence for contamination of Well 5 was entirely consistent and the most plausible explanation for the outbreak.

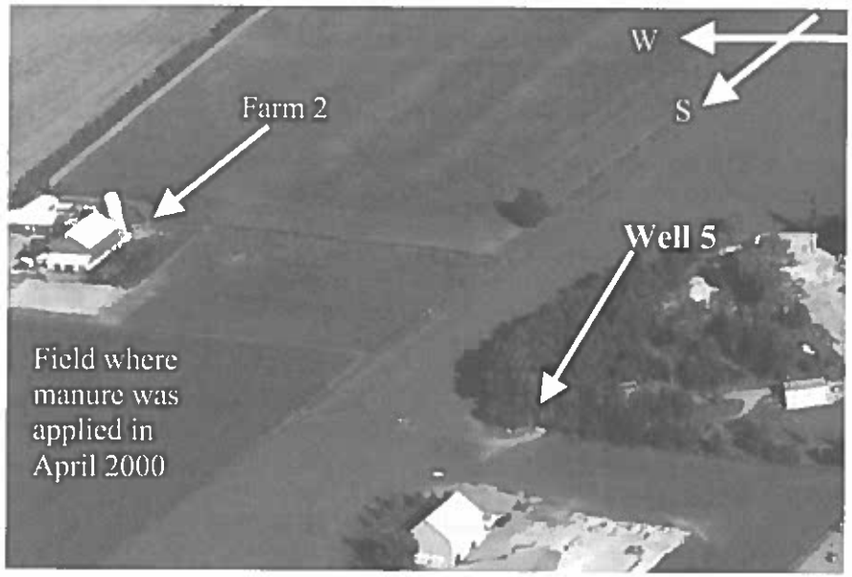

Figure 4.2 Location of Walkerton PUC Well 5 near farms to south and west (adapted from original photo taken for the Walkerton Inquiry by Constable Marc Bolduc, RCMP, used with permission)

The epidemiologic evidence and the timing of illness in the community strongly suggested that contamination occurred on or about May 12. Well 5 was the major source of water to Walkerton between May 10 and 15, with intermittent contributions from Well 6. The heavy rainfall experienced by Walkerton on May 12 peaked between 6 p.m. and midnight. Bacteriological sampling data were limited and were confounded by the inaccurate labeling practiced by PUC personnel. Given the location of the PUC shop in the distribution system downstream of Well 5, combined with the documented poor practices of the PUC operators, it was likely that the May 15 sample labeled *Well 7 treated* was actually taken at the PUC shop and represented Well 5 water entering the distribution system. This sample, the one that Stan

Koebel concealed from health authorities, was heavily contaminated with greater than 200 *E. coli* per 100 mL.

A number of samples were collected by the local Health Unit, the MOE and the PUC between May 21 and 23. All Well 5 samples were positive for both total coliforms and *E. coli* while neither Well 6 nor Well 7 samples were positive for either bacterial indicator. A June 6 sample taken from the spring adjacent to Well 5 had a count of 80 *E. coli* per 100 mL. Pump tests were done at two monitoring wells near Well 5, including one on the adjacent farm, in late August 2000. After the 32-hour pump test, *E. coli* counts climbed to 12,000 per 100 mL on the monitoring well 225 m west of Well 5 and to 900 per 100 mL on the monitoring well 105 m west-northwest of Well 5. Dr. R. Gillham, the hydrogeology expert called by the Inquiry, concluded that a large area of the shallow aquifer supplying Well 5 had been heavily contaminated.

In addition to the reasonably consistent circumstantial evidence implicating Well 5 as the primary, if not sole, source of microbial contamination of Walkerton's water supply, there was reasonably compelling evidence linking the bacterial pathogens that caused the human illness with cattle and manure samples from the farm near Well 5. Dr. A. Simor, the Inquiry's expert on medical microbiology, described how pathogens were characterized in the laboratory (A. Simor, W.I. Transcript, February 26, 2000, pp. 142-146). Three methods were used to gain more evidence about the specific strains of pathogens identified: phage typing, serotyping and pulsed-field gel electrophoresis (PFGE).

The first method exploits the ability of certain viruses to infect bacteria. These viruses are named bacteriophages — phages for short. Different bacteria are susceptible to infection by different phages, so exposing a strain of bacteria to a range of different phages can be used to type that strain for its susceptibility to phage attack. That pattern of phage susceptibility can be used to distinguish one strain of bacteria from another strain of the same species.

The second method, serotyping, relies on detecting specific antigens on the exterior of a bacterial cell. These include O antigens that characterize components of the bacterial cell walls and H antigens that characterize the flagella (the whip-like tails that bacteria use for motion). For example, the name *E. coli* O157:H7 refers to the strain of *E. coli* with the 157 antigen in the cell wall and the 7 antigen in the flagellum. Individual strains of *Campylobacter* species, such as *C. jejuni*, can also be characterized by serotyping.

The third method, PFGE, looks at the molecular properties of the DNA found in a bacterial strain. Because the DNA provides the genetic material that causes specific strains of a bacterial species to be distinct, evaluating and comparing the DNA of individual strains provides a relatively direct method

for identifying specific strains. In this procedure, DNA is extracted from the bacterial cell and is cut at chosen locations using specific enzymes to yield DNA fragments of varying size. These fragments are separated on a gel plate by electrophoresis to yield a pattern of bands distributed according to the relative size of the fragments. The resulting pattern can be interpreted in terms of the original DNA structure to compare with DNA from different strains. Identical strains will have identical DNA fragment patterns, while the patterns of closely related strains may differ in only a few fragments. Dr. Simor's expert opinion at the Inquiry (A. Simor, W.I. Transcript, p. 160, Feb 26) was that strains differing by six or fewer DNA fragment bands are considered genetically related in the context of a common source for an outbreak. These advanced methods were used to compare pathogens recovered from cattle manure with those from infected humans.

By August 31, 2000, in the follow-up investigation, the outbreak team working for the Health Unit had identified 1,730 cases as suspected cases (BGOSHU, 2000). Following contact attempts by phone or mail, 80% of contacts were judged to have an illness related to exposure to Walkerton municipal water, and 1,346 cases met the definition adopted for the investigation. "*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 the primary case defined above. A person was classified as unknown if their exposure status was not indicated.*" (BGOSHU, 2000).

Of these cases, 675 had submitted stool samples for culture, yielding 163 positive for *E. coli* O157:H7, 97 positive for *C. jejuni*, 7 positive for *C. coli* and 12 positive for both *E. coli* O157:H7 and *Campylobacter*. The epidemic curve is plotted in Figure 4.3.

The second peak in the epidemic curve (Figure 4.3) has been discussed as possibly representing the second of two types of infection that occurred, with *C. jejuni* and with *E. coli*. Another possibility that was not discussed is that the second peak occured on May 23, the date that Dr. McQuigge gave his first press conference on the outbreak. The resulting high profile media coverage that day might have anchored May 23 in the memories of some victims when they responded to the survey performed later to determine the date of onset of illness for each case.

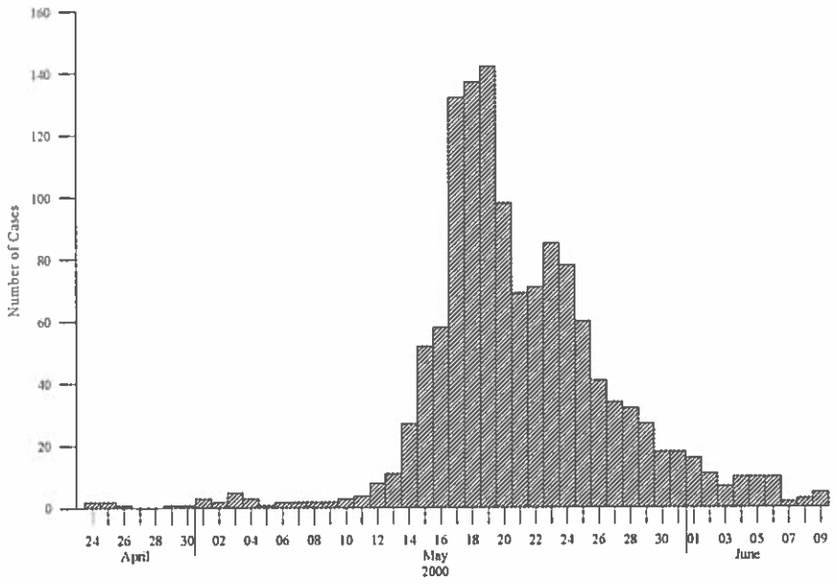

Figure 4.3 Date of onset for cases of acute gastroenteritis – Walkerton (Source: BGOSHU, 2000, reproduced with permission of Grey-Bruce Health Unit)

Various cultures were also done on environmental samples, allowing some comparison with the pathogens causing illness. The Health Unit collected samples from 21 sites in the Walkerton distribution system on May 21 and collected raw and treated water from Well 5 on May 23. Concurrent samples taken at Wells 6 and 7 showed neither total coliforms nor *E. coli*. Two of the distribution system sites remained positive for total coliforms and *E. coli* over several days. One of the distribution system sites, along with cultures from the May 23 raw and treated water samples from Well 5, was analyzed by PCR, another molecular diagnostic technique. This technique is able to amplify DNA from a sample to allow extremely sensitive detection for specific genes that may be present. Using PCR, these samples, representing a contaminated location in the Walkerton distribution system and Well 5, all showed the same genes for O157, H7 and the specific verotoxin, VT2.

Working with Health Canada and the Ontario Ministry of Agriculture and Food, the Health Unit undertook livestock sampling on farms within a 4 km radius of each of Wells 5, 6 and 7 between May 30 and June 13 (BGOSHU, 2000). They obtained livestock fecal samples from 13 farms and found human pathogens (mainly *Campylobacter*) in samples from 11. On two farms, both *C. jejuni* and *E. coli* O157:H7 were found. These farms were selected for further

sampling on June 13. The results are summarized in Table 4.2. Farm 1 was located in the vicinity of Wells 6 and 7 and Farm 2 was located within sight of Well 5 (Figure 4.2).

Table 4.2 Culture results from two farms re-sampled on June 13 (derived from data reported in BGOSHU, 2000)

	Number Positive	
Pathogens	Farm 1	Farm 2
E. coli O157: H7	2	6
C. jejuni / coli	8	9
both	2	–

The most telling features of these typing efforts are revealed in Table 4.3, which compares the strain characteristics from the cattle fecal samples at the two farms with the cultures from human cases infected with *E. coli* O157:H7 or *Campylobacter* spp. Details of the extensive strain typing work that was done have now been published by Clark et al. (2003).

Table 4.3 Pathogen strain typing comparison between human cases and cattle fecal samples at farms 1 and 2 (derived from data reported in BGOSHU 2000)

		Cattle Fecal Samples	
	Human Cases	Farm 1	Farm 2
Total individuals tested	675	20	38
E. coli O157:H7 positive	163	4	6
phage type 14	147 (90% of +)	0	6 (100% of +)
phage type 14a	3 (2% of +)	4 (100% of +)	0
PFGE pattern A	150 (92% of +)	0	6 (100% of +)
PFGE pattern A1	2 (1.2% of +)	4 (100% of +)	0
PFGE pattern A4	2 (1.2% of +)	0	1 (17% of +)
verotoxin VT2	majority	–	6 (100% of +)
Campylobacter spp. positive	105	8	9
phage type 33	56 (53% of +)	0	9 (100% of +)
other phage types 2, 13, 19var, 44, 77		8 (100% of +)	0

These results do not provide absolute confirmation that manure from Farm 2 was responsible for contamination of the Walkerton water supply for a number of reasons. The cattle samples were taken in mid-June, about a month after the suspected date of contamination, and it is not possible to be certain that cattle on Farm 2 were infected on May 12. Likewise, the DNA typing by PFGE must be recognized as much less certain than DNA typing used in human forensic analysis. Because bacteria reproduce by binary fission, each progeny cell is a clone of its parent (i.e., each progeny cell has identical DNA to the parent cell, so individual cells are not genetically unique). However, the DNA makeup of bacteria changes rapidly because their rapid rate of reproduction allows genetic mutation through a number of mechanisms that alters their DNA quickly compared with humans. In total, the level of evidence for this outbreak is far more compelling than the quality and level of evidence that has historically been available for outbreak investigations. The main features suggesting that Farm 2, located near Well 5, was the primary source of pathogens that caused the outbreak are the match of the phage type 14 for *E. coli* O157:H7, with PFGE pattern A and with phage type 33 for the *Campylobacter* spp.

Finding that raw water in Well 5 was contaminated by pathogens detected in cattle manure from a nearby farm does not explain how this contamination was allowed to cause the disastrous disease outbreak in the community. The water produced by all the wells serving Walkerton was supposed to be chlorinated continuously to achieve a chlorine residual of 0.5 mg/L for 15 minutes of contact time (ODWO). This level of disinfection would have provided a concentration-contact time (CT) value of 7.5 mg/L-min. That CT value is more than 150 times greater than literature CT values of 0.03-0.05 mg-min/L for 99% inactivation of *E. coli* O157:H7 and more than 80 times greater than a CT value of 0.067 to 0.090 mg-min/L for 99.99% inactivation of *E. coli* (Hoff & Akin, 1986; Kaneko, 1998). Clearly, the specified level of chlorine residual and contact time was not operative for Well 5 in May 2000. If it had been, inactivation of the *E. coli* pathogen greater than 99.99% would have been achieved, a level of protection that is certainly not consistent with the magnitude of the outbreak that occurred in Walkerton.

Chlorination practices in Walkerton did not follow the specifications of the ODWO. The operators did not regularly measure chlorine residuals as they should have; rather, they often entered fictitious readings on their data log, as was done during the time of the outbreak. The chlorine dose administered at Well 5 was actually estimated to have been less than 0.5 mg/L. One estimate was 0.4 mg/L, based on dilution practices followed and the capacity of the pump for delivering the diluted hypochlorite solution used; another estimate was 0.44 mg/L, based on average chlorine consumption records (O'Connor, 2002a, p.155). Even in the absence of any chlorine demand, the chlorination practices at Walkerton Well 5 would not have provided the required 0.5 mg/L for 15 minutes. Given the massive manure contamination that likely washed into Well 5 during the heavy rains on May 12, there would have been a

substantial, if not overwhelming, chlorine demand from manure-associated organic matter. The contamination-related demand could easily consume the inadequate chlorine dosage, leaving no chlorine residual and no effective disinfection.

The evidence available did not provide a basis to estimate precisely the magnitude of contamination that entered Well 5 on or about May 12. The finding in August 2000 of substantial *E. coli* contamination of the aquifer supplying Well 5, combined with the microbiological typing evidence relating the pathogens in the nearby farm to those responsible for the outbreak, made a reasonably compelling case for Well 5 being the source of contamination of the Walkerton drinking water system. Overall, the evidence about contamination source combined with the inadequate chlorination practices of the PUC personnel provided a consistent and persuasive explanation for how the fatal contamination of the Walkerton water supply occurred.

4.2.5 Commentary

Justice O'Connor conducted the most thorough inquiry into drinking water safety ever undertaken in Canada. In terms of being a detailed and thorough analysis of institutional failures, the Walkerton Inquiry was likely the most complete inquiry ever undertaken of the drinking water industry and government regulators anywhere. Among the 114 witnesses summoned to give sworn testimony before the Inquiry were two mayors, five assistant deputy ministers, four deputy ministers, two former ministers of environment and the Premier of Ontario.

The Inquiry issued a comprehensive document request to the Government of Ontario and had the Royal Canadian Mounted Police (RCMP) exercise search warrants to acquire more than a million documents that were ultimately reviewed by Commission Counsel. This overwhelming body of evidence and the remarkable circumstances involved in the Walkerton tragedy gave rise to many important conclusions by Justice O'Connor (O'Connor, 2002a). Some of the key findings directly applicable to the purpose of this book are summarized and discussed below.

The operators at Walkerton engaged in many inexcusable activities, including intentionally failing to use adequate doses of chlorine, or using no chlorination at all, failing to measure the chlorine residual, making false entries about chlorine residuals in their daily operating logs and misstating where they had collected samples. The operators knew that these actions were contrary to the requirements specified by the MOE. The failure to disclose the contaminated sample results for May 15, received on May 17, to public health authorities in response to direct questions about water safety asked between May 19 and May 23 was particularly irresponsible. Likewise, the failure to admit that Well 7 had been allowed to run without chlorination from May 15 to 19 was clearly inexcusable. Yet the operators involved continued to drink the water themselves throughout this disaster, suggesting they simply did not understand the grave danger their actions and inaction posed for the public they were employed to

serve. They often drank untreated water from Well 5 because it appeared clean and clear, and "*always tasted better than the treated* [water]" (O'Connor, 2002a, p.193).

Stan Koebel testified that one reason they kept the chlorine residual lower than required was because town residents complained from time to time that the water contained too much chlorine, giving the water an offensive taste. Some insights and perspectives, at an individual human interest level, have been published about how Stan Koebel, who was arguably an otherwise decent citizen of Walkerton, could have made so many bad decisions (Perkel, 2002).

Given the behaviour revealed by the Inquiry evidence, the Government of Ontario position that this tragedy was entirely the fault of the operators and their employers, the Walkerton Public Utilities Commission, was perhaps not surprising. However, that position was rejected by the Commissioner of the Inquiry (O'Connor, 2002a, p.24): "*It is simply wrong to say, as the government argued at the Inquiry, that Stan Koebel or the Walkerton PUC were solely responsible for the outbreak or that they are the only ones who could have prevented it.*"Understanding the basis for this finding requires an appreciation of the scale of institutional failure that surrounded the actions of the operators. The contamination of Well 5 almost certainly came from manure at the nearby farm. The owner had followed exemplary farm environmental practices. The Inquiry report was very clear that this farm was not at fault for what happened.

Continuous chlorine residual monitors should have been installed at Well 5, where they would have been able to prevent the outbreak by shutting the system down if a chlorine residual could not be maintained in the face of an overwhelming chlorine demand from raw water contamination. The failure to require continuous chlorine residual monitors at Well 5 arose from deficiencies in the approvals and inspections programs of the MOE. In 1994, Ontario had adopted a policy (ODWO, 1994 revisions, s. 4.2.1.1) that drinking water systems, without filtration, using groundwater under the direct influence of surface water, must continuously monitor chlorine residual. The evidence that Well 5 was a system directly under the influence of surface water had been in hand from the time of the hydrogeologist's report (Wilson, 1978) commissioning the well. Monitoring results over the years continued to confirm this vulnerable status of Well 5. The water operators in Walkerton had neither the training nor the expertise needed to recognize the vulnerability of Well 5 to surface contamination, nor the possible consequences of that contamination. These operators did not comprehend the importance of measuring chlorine residual to provide a real-time measure of successful disinfection or alternately, a real-time measure of water contamination when it had occurred. Even without continuous chlorine residual measurement, the operators could have substantially reduced the scope of the outbreak if they had measured chlorine residual daily, as they were supposed to do, and had understood the implications of not being able to achieve the required chlorine residual with the application of a reasonable chlorine dose.

The MOE inspections program found a number of deficiencies in the operation of the Walkerton water system over the years, but the MOE failed to take meaningful and consistent follow-up action to correct those deficiencies. The falsified chlorine residual records often reported values of exactly 0.50 mg/L or 0.75 mg/L for every day of the month. Evidence at the Inquiry was given that in 1999 virtually every chlorine residual measurement recorded was false. Besides the obvious lack of credibility of such consistent records at their face value, when MOE inspectors measured chlorine residuals, they would find lower values than had been recorded. Finally, evidence was presented to the Inquiry that the capacity to dose chlorine at Well 5 was below 0.5 mg/L, so that maintaining a chlorine residual at 0.5 mg/L was not possible.

The commissioners of the Walkerton PUC, the Mayor and Council Members, were unaware of the improper treatment and monitoring practices of their operators. However, they failed to respond properly when they were notified by the MOE that the last inspection in 1998 had noted deficiencies and had requested action by the Walkerton PUC to correct those deficiencies. There was no evidence that the commissioners had discharged their responsibilities to their public by ensuring that the PUC employees were doing properly the job they were being paid to do.

The Bruce-Grey-Owen Sound Health Unit responded diligently to the outbreak as their personnel learned of the emerging disaster. Some town officials criticized the Health Unit for failing to issue a boil water advisory before May 21. Having been misled about the safety of the water by Stan Koebel, the Health Unit deserves credit for issuing the boil water advisory on May 21 even though they were being reassured that the water was "*okay*." In retrospect, given the scale of the outbreak, it is now apparent that the Health Unit should have been more aggressive in notifying the residents of Walkerton on the Sunday of a holiday long weekend. Yet compared with some of the case studies to follow and given the misinformation provided by the water utility, the actions that were taken on May 21 are commendable. Any deficiencies that are apparent in retrospect speak mainly to the need for better advance preparation and coordination among the responsible parties to ensure effective action when disaster strikes.

The Health Unit fared less well in terms of the attention their personnel paid to drinking water safety in general. Staff apparently accepted that the MOE was the lead agency and the MOE deficiency reports on Walkerton that had been received over the years did not trigger any action or interest on the part of the Health Unit to assure that the deficiencies were being resolved. For its part, the MOE showed no interest in involving or informing the Health Unit in dealing with drinking water safety issues, even as the May 2000 outbreak was happening and the serious health implications were obvious.

The MOE had undergone massive budget cuts over the previous decade (1990–91 to 1999–00). Annual operating expenditures for the MOE dropped by 52% (from $363 million to $174 million) and personnel by 40% (from 2,306 to 1,374). These cuts

cannot explain the early inadequacies in regulating Well 5, dating back to 1978, but they did make it less likely that the MOE would recognize and act upon the deficiencies in Walkerton that were apparent in the years immediately before the outbreak.

The budget cuts also involved discontinuation of provincial government laboratory testing services for municipalities in 1996. Ontario's Provincial Medical Officer of Health and others warned the Government of Ontario that a regulation to require private labs to report adverse results to Health Units and the MOE was necessary if government laboratory testing was privatized. The failure to act on this warning contributed directly to the delay in issuing the boil water advisory in Walkerton. If an effective requirement had been in place, the Health Unit and the MOE would have known about the adverse result on May 17 and would have issued a boil water advisory no later than May 19 when illness was becoming evident in the community. The Inquiry estimated that this earlier warning might have prevented 300 to 400 cases of illness, but would not likely have prevented any of the deaths.

Stan and Frank Koebel had developed extensive experience in running the water system for Walkerton and, apparently, maintained consistent delivery of adequate quantities of water to the town's residents. However, it was clear that they had no understanding of the health risks posed by contaminated drinking water, the vulnerability of Well 5 to serious contamination or the critical role that chlorination played as the only barrier between contaminated water from Well 5 and the community. These operators showed limited competence to run this system under normal conditions, but they lacked any meaningful understanding of the quality and safety issues for their water supply or how to respond to a serious threat to the safety of this supply.

Ontario began a voluntary certification program for water treatment operators in 1987. Those with experience and basic education (not necessarily any specific training) could be certified without meeting any examination requirements under a grandparenting provision. Operators who were certified under this program were not required to meet any further requirements to renew their licenses. Certification of water treatment operators became mandatory in Ontario in 1993, but both Stan and Frank Koebel were able to apply and have their earlier certification applied to the new program; because they had entered under the voluntary program, they were not subjected to any subsequent examination. Grandparenting of some form was a feature of all operator certification programs in Canada at that time and was also common in the U.S., even to the extent of legislation making grandparenting mandatory to protect existing employees (O'Connor, 2002a, p.341). The mandatory operator certification introduced in 1993 specified that all operators, even previously certified ones, be required to take 40 hours of training each year, but the content and form of training was not specified, leaving it up to operators to create their own interpretation of training for this purpose. Finally, there was no enforcement of the training requirement

evident in the case of the Koebel brothers. Justice O'Connor noted that operator training should have clearly addressed and emphasized the public health aspects of delivering safe water, but there was no indication of this training being required or provided.

The consequences of the Walkerton outbreak have reached beyond the 2,300 cases of illness and 7 deaths. The Inquiry estimated the economic impact on the Walkerton community at more than $64 million, arising from a wide variety of causes, from restaurants being forced to close, local accommodation providers losing bookings, retail stores losing business (to less than 10% of normal in some cases) and real estate values dropping. Some Walkerton residents experienced negative treatment in neighbouring communities, as if they were infectious and posed a contagious threat to the health of others.

The total expenditures of the Ontario government directly arising from Walkerton has likely been several hundreds of millions of dollars, covering costs ranging from $12 million to decontaminate the Walkerton system and lease a temporary membrane filtration system to settlement of a class-action law suit. Municipal liability insurance rates across Canada have increased because most municipalities are responsible for drinking water.

Readers from outside Ontario or Canada learning about everything that went wrong in Walkerton might find it easy to dismiss the Walkerton outbreak as an aberration that happened elsewhere. For those readers who may be inclined to view the Walkerton story in this way, we invite you to read through the next 69 case studies.

If, after reading about all of the other factors that have gone wrong to cause outbreaks in 15 different affluent nations, you are truly certain that none of this could ever happen to you, then congratulations! To be justified in being certain, you must know your system very well and you must understand all of the ways that things can go wrong. You must have effective and well-practised plans in place for dealing with the many problems, large and small, that can happen if you are to be truly confident about avoiding a Walkerton-style disaster. However, we suspect that those of you most likely to avoid encountering such problems will be those who are willing to believe that Walkerton-style problems *could* happen. The choice seems clear: unwarranted peace of mind or nervous confidence underlying the vigilance necessary to forestall a future appearance before a Walkerton-like Inquiry.

4.3 OUTBREAKS IN THE 1970s

4.3.1 Overview

The 1970s saw dramatic changes for the drinking water industry in affluent nations. At the start of the decade, public health and sanitary engineering courses were taught as if all knowledge needed for safe drinking water was already in hand; academic research into drinking water quality or safety had a low profile. The combination of coagulation, filtration and disinfection, mainly by chlorination, was generally considered full treatment for drinking water.

During the 1970s, trace organic analysis with gas chromatography, linked to electron capture and mass spectrometry detection, dramatically improved analytical sensitivity to allow the detection of numerous trace organic compounds in treated drinking water supplies. These advances profoundly disturbed our perceptions of drinking water quality and safety.

In the U.S., a study for the Environmental Defense Fund (EDF) suggesting cancer mortality for those consuming treated drinking water from the Mississippi River was higher than for those consuming drinking water from groundwater sources attracted enormous attention (Harris & Page, 1974). This was reinforced by a U.S. EPA report within the same week that the New Orleans water supply drawn from the Mississippi River contained a number of trace organics, many of which were suspected carcinogens (U.S. EPA, 1974). These events preceded by only five days a House of Representatives vote on the new Safe Drinking Water Act, providing a vote margin of 296 to 85, sufficient to override a threatened Presidential veto (Marx, 1974). On December 16, 1974, the President signed the Safe Drinking Water Act (SDWA) into law, including a specific requirement for the U.S. EPA to conduct a national survey of municipal water supplies for the presence of halogenated organics.

Meanwhile, in Europe, Johannes Rook (1974) had already reported that chloroform and the other THMs were found at higher concentrations in chlorinated drinking water than in raw surface water supplies. He provided meticulous evidence for his hypothesis that the THMs were produced by reactions between chlorine and naturally occurring organic matter in water. Rook's discovery, made years earlier using his experience analyzing volatile flavour components in beer, was soon corroborated by Bellar et al. (1974). Working entirely independently at the U.S. EPA, they found higher levels of THMs with increasing chlorine contact during disinfection. An insider account of the emergence of disinfection by-products as a drinking water

Safe Drinking Water

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