Chapter 4 The Physical Causes of the Contamination

Contents

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4.1 Overview

The physical causes of the contamination of the Walkerton water system in May 2000 were the subject of extensive evidence. In this chapter, I consider a variety of possible sources, including the three municipal wells operating in May 2000, watermain construction along a section of Highway 9, possible interference with the integrity of the distribution system, and the application of biosolids or septage near municipal wells. In determining the causes, I review several important sources of information, including the geology and hydrogeology of the surrounding area, information respecting possible sources of the *Escherichia coli* and *Campylobacter* contamination, meteorological data, bacteriological sample results, records of the location of each well and the volume of water pumped by it, and epidemiological data.

I conclude that the primary, if not the only, source of the contamination was manure that had been spread on a farm near Well 5, although I cannot exclude other possible sources. The manure was applied in late April 2000, before a period of significant rainfall occurring from May 8 to 12. The survival time of *E. coli* in soil is such that large numbers of *E. coli* on the farm could easily have survived after the manure application. DNA typing of the animals and the manure on the farm revealed *E. coli* O157:H7 and *Campylobacter* strains on the farm that matched the human outbreak strains predominating in Walkerton in May 2000. An August 2000 test demonstrated that as Well 5 pumped, *E. coli* levels increased in Well 5 as well as in two monitoring wells between the farm and Well 5. I note at the outset that Dr. David Biesenthal,[1] the farm's owner, engaged in accepted farm practices and cannot be faulted for the outbreak.

I conclude that the entry point of this contamination into the municipal drinking water supply was through Well 5. The overburden in the area of Well 5 was shallow, and there were likely direct pathways – such as fence post holes and a reversing spring by the north side of Well 5 – through which the contamination travelled from the surface to the bedrock and the aquifer.

Further, Well 5 was a shallow well, whose casing extended only 5 m below the surface. All of the water drawn from the well came from a very shallow area

[1] Dr. David Biesenthal is a veterinarian.

between 5.4 m and 7.7 m below the surface. More significantly, this water was drawn from an area of highly fractured bedrock. This fracturing, and the geological nature of the surrounding bedrock, made it possible for surface bacteria to quickly enter into fractured rock channels and proceed directly to Well 5. Raw water contamination by coliforms and fecal coliforms was indicated in the initial pump tests in 1978 and continued to May 2000.

In the immediate aftermath of the tragedy, samples of raw water taken at Well 5 consistently tested positive for *E. coli*. Significantly, neither Well 6 nor Well 7 samples tested positive for *E. coli* during this period. The only distribution system samples testing positive for *E. coli* were from two "dead ends" that were closer to Well 5 than to the other two active wells. A positive *E. coli* sample from June 6, 2000, taken from a spring discharging near Well 5, indicated that a large area of bedrock underlying Well 5 was contaminated.

The experts who testified at the Inquiry all agreed that there was "overwhelming evidence" that contamination entered by way of Well 5. I am satisfied that although Well 6 and, to a lesser extent Well 7, may be vulnerable to surface water contamination, the overwhelming evidence points to Well 5 as the source of the Walkerton system's contamination in May 2000.

It is not possible to determine the exact time when contamination first entered the water distribution system. However, I conclude that the residents of Walkerton were probably first exposed to the contamination on or shortly after May 12. It was at this time that Well 5 was the primary supply well, contributing the most significant amounts of water to the distribution system. This conclusion is supported by the epidemiological evidence, the evidence of the health care institutions that treated the ill and vulnerable groups, anecdotal evidence from residents, and the timing of the heavy rainfall. It is also consistent with the findings of the Bruce-Grey-Owen Sound Health Unit and of Health Canada, which both concluded that the predominant exposure dates were between May 13 and May 16, 2000.

The applicable government technical document relating to disinfection, the Chlorination Bulletin, states that a water system like Walkerton's must treat well water with a chlorine dose sufficient to satisfy the chlorine demand caused by substances in the raw water and to sustain a chlorine residual of 0.5 mg/L after 15 minutes of contact time. The evidence is clear that if such a chlorine residual had been maintained at Well 5, considerably more than 99% of bacteria such as *E. coli* and *Campylobacter* would have been killed. For practical purposes this would have prevented the outbreak.[2]

In May 2000, the operators of the Walkerton water system chlorinated the water at Well 5, but routinely used less chlorine than was required. The incoming contamination overwhelmed the chlorine being added. However, the amount of contamination was likely so great that the demand it put on the chlorine would have overwhelmed even the amount of chlorine needed to maintain a residual of 0.5 mg/L after 15 minutes of contact time under normal conditions.

Nonetheless, the outbreak could have been prevented. Walkerton did not have continuous chlorine residual or turbidity monitors at Well 5. Such monitors could have sounded an alarm and shut off the pump when the chlorine residual dropped.[3] Compounding this shortcoming, the Walkerton operators did not even manually monitor the chlorine residual levels daily during the critical period. Daily monitoring would very likely have enabled the operators to take steps to significantly reduce the scope of the outbreak.[4]

As the contaminated water spread through the system, people began to fall ill. The epidemiological data establishes that individuals started to experience symptoms around May 16 or 17, indicating an exposure date beginning on May 12 or soon afterward. This is consistent with the conclusion that significant rainfall from May 8 to 12 probably caused the contamination from the farm manure to enter the aquifer and then spread to Well 5. The first test results indicating *E. coli* contamination in the system were collected on May 15. On May 19, the Walkerton Public Utilities Commission (PUC) began to flush and superchlorinate the system, and a boil water advisory was issued by the local Medical Officer of Health on May 21.

At the end of this chapter, I review and reject a number of other possible sources of the contamination, including new construction, breaks, repairs, and cross connections in the distribution system, and the spreading of biosolids.

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[2] This statement is subject to the qualification that a large increase in turbidity accompanying the contamination may have prevented the chlorine from disinfecting the contaminants. In my view, it is most unlikely that this is what happened in May 2000.

[3] It would have been necessary to have a continuous turbidity monitor because it is possible, although very unlikely, that an increase in turbidity would have accompanied the contamination, thus interferring with the effective operation of a continuous chlorine residual monitor.

[4] I note that it would not be difficult for any properly trained water operator to appreciate the significance of the low or non-existent chlorine residuals and to take the appropriate corrective action.

4.2 The Multi-Barrier Approach to Municipal Water Systems

Before turning to a discussion of the circumstances giving rise to the outbreak in Walkerton, it is useful to briefly describe the multi-barrier approach to ensuring the safety of drinking water in communal or municipal water systems.

Experts at the Inquiry repeatedly stated that a multi-barrier approach is necessary to ensure safe drinking water. This approach includes at least five elements: the source of the water, water treatment, the distribution system, the monitoring of water quality, and the response to adverse water test results.

4.2.1 Source

Drinking water comes mainly from two types of sources: groundwater (e.g., wells and springs), and surface water (e.g., lakes, rivers, and reservoirs). Groundwater is often the source of drinking water in smaller communities, as is the case in Walkerton. Larger communities in Canada, such as the City of Toronto, are more often supplied with surface water.

Groundwater is generally considered to be less prone to microbial contamination than is surface water, because as groundwater travels through the subsurface, a filtration of particles occurs, including the filtration of micro-organisms. The travel times for groundwater may be very long, making sudden microbial contamination even less likely. As a result, groundwater may require less treatment than surface water does. In some circumstances, however, groundwater may be "under the direct influence" of surface water: surface contamination can travel rapidly through natural cracks, fractures, or surface features such as springs or ponds to gain direct access to groundwater. When this occurs, groundwater should be treated and monitored with the same concern for sudden microbial contamination as is the case with surface water.

4.2.2 Treatment

The main purposes of water treatment are to ensure that the water is safe to drink and that it is aesthetically pleasing, with good taste and no odour.

The treatment of water attempts to eliminate three classes of contaminants: (1) microbial contaminants such as bacteria (e.g., *E. coli*), viruses, and protozoa (e.g., *Giardia* and *Cryptosporidium*); (2) chemical contaminants (e.g., metals and pesticides); and (3) radiological contaminants.

Guidelines providing baseline safety standards have been developed by the federal, provincial, and territorial governments to address microbial, chemical, and radiological parameters in drinking water. At the material times, these guidelines appeared in two publications of the Ministry of the Environment (MOE): the Ontario Drinking Water Objectives (ODWO) and the Chlorination Bulletin.

Disinfection is a treatment process designed to inactivate harmful or disease-causing organisms. In North America, chlorination is the most common method of disinfection. When chlorine is added to untreated or "raw" water, it reacts with many common substances, including ammonia, iron, and organic material (including micro-organisms such as bacteria). In sufficient amounts, chlorine can inactivate disease-causing micro-organisms.

The amount of chlorine added to disinfect water is known as the "chlorine dose." Reactions, including those that inactivate micro-organisms, will consume some or all of the chlorine dose. These chlorine-consuming reactions are called "chlorine demand." The chlorine dose minus the chlorine demand provides the "chlorine residual." The presence of a chlorine residual, after enough time has passed for the chlorine-consuming reactions to be completed, indicates that there was a sufficient amount of chlorine available to react with all of the chlorine-demanding substances, including the micro-organisms.

Section 3.1.2 of the Chlorination Bulletin (applicable in May 2000) provides that a total chlorine residual of at least 0.5 mg/L after 15 minutes (preferably 30 minutes) of contact time before the water reaches the first consumer "will" be provided at all times. It states that it is preferable that "most of the residual be a free residual." A free chlorine residual is the most effective disinfecting agent; it must be contrasted with a total chlorine residual and a combined chlorine residual. When chlorine is added to water, it dissociates into hypochlorous acid and hydrochloric acid. Hypochlorous acid is the compound that is the prime disinfecting agent in a free chlorine residual. However, it is very reactive and will quickly combine with other compounds (e.g., ammonia) to produce chloramines, which provide a "combined chlorine residual" and lower the free residual. Although a combined chlorine residual is more stable and has disinfectant ability, it will not act as quickly to destroy bacteria as will a free chlorine residual. The total chlorine residual less the free chlorine residual is the combined chlorine residual.

A failure in the treatment process can occur if equipment malfunctions or if there is a sudden change in the quality of the water and the treatment process cannot respond quickly enough to the change in source water quality. When the amount of contamination entering the system suddenly increases, the chlorine demand usually rises. If the chlorine dose is not increased to exceed the chlorine demand, the chlorine residual decreases. Where a fixed chlorine dose has been injected, a decrease in the chlorine residual level indicates increased chlorine demand in the water, a situation commonly caused by organic contamination.

Additional treatment barriers, such as coagulation, sedimentation, and filtration, are often required for surface waters when chlorine disinfection alone does not provide for the adequate safety of the water supply.

4.2.3 Distribution System

The distribution system is the network of pipes between the water source/ treatment system and the consumer's plumbing system. It also includes the storage of treated water in water towers and reservoirs. The fact that a distribution system itself exerts a chlorine demand heightens the need to maintain a chlorine residual. In addition, contamination of the distribution system can occur as a result of watermain breaks, the construction of new mains, or the infiltration of water from the surrounding ground into the distribution system pipes.

In recent years, there has been an increased emphasis on the quality of the water in the distribution system. The longer water remains in the distribution system, the greater the risk of its quality deteriorating. It is believed that for a distribution system to be secure, it should be built with as few dead ends as possible because dead ends inhibit water circulation and create an increased risk of nuisance bacterial growth and related water quality deterioration.

4.2.4 Monitoring

Monitoring involves the collection of samples and the taking of measurements to ensure that the system is working properly and that the water is safe. It focuses on health-related parameters such as the presence of bacteria as well as on aesthetic parameters.

Monitoring generally involves two components: (1) monitoring of raw water and treatment process performance (e.g., the measurement of chlorine residual or turbidity); and (2) the monitoring of the actual product – the treated water. Because it is virtually impossible to monitor all possible harmful organisms, "indicator organisms" are monitored; they indicate the possible or likely presence of a disease-causing organism. In microbiological monitoring, for example, the total coliforms test measures a broad grouping of various bacteria, including those associated with fecal contamination. If total coliforms are found in water samples, additional tests are conducted to determine if fecal contamination of the water has occurred. Because most water-borne diseases are caused by microorganisms in fecal wastes, such a contamination of drinking water constitutes an unacceptable risk.

In addition to stipulating the primary disinfection process, the Chlorination Bulletin also provides that "a chlorine residual should be maintained in all parts of the distribution system." This has generally been interpreted to mean that a detectable residual should be present in the distribution system.

4.2.5 Response

This component of the multi-barrier approach involves appropriate responses to failing process measures or adverse water quality. For example, the failure to detect a chlorine residual indicates that the chlorine dose is insufficient to meet the chlorine demand, in which case, the disinfection may have failed. Specific notification and operational procedures exist for adverse quality measures such as microbiological results. These procedures include further sampling to confirm an adverse result, flushing watermains, and increasing the disinfectant dose. Another possible response to adverse results is issuing a boil water advisory.

In summary, the multi-barrier approach includes five elements designed to ensure safe drinking water in communal systems: a good source of water, effective treatment of the water, a secure distribution system, continuous monitoring of the system, and an appropriate response to adverse results.

4.3 Well 5

4.3.1 Warning Signs at the Time of Construction

From its inception, Well 5 was recognized as a vulnerable well that might be under the direct influence of surface water. I find, however, that no appropriately thorough analysis of the well's vulnerability was conducted from the time of its construction in 1978 until the tragedy of May 2000. I discuss below the initial hydrogeological and bacteriological results obtained at the time of Well 5's construction that indicated surface water influence.

Before bringing Well 5 online, Ian D. Wilson Associates Ltd., professional engineers, submitted a report, "Testing of the Town of Walkerton Well 4," dated July 28, 1978.[5] The length of the well casing was 18 feet (5.5 m). The Wilson report noted that the well had two water-bearing zones: one at 18–19 feet (5.5–5.8 m) and another at 23–24 feet (7.0–7.3 m). The geological materials at 18–19 feet (5.5–5.8 m) were noted to be "brown broken soft limestone" and, at 23–24 feet (7.0–7.3 m), "brown very fractured, soft limestone." The area from 0–8 feet (0–2.4 m) was brown, sandy, mixed clay with stones and mixed sand with gravel, and from 8–13 feet (2.4–4.0 m) it was brown, broken, soft limestone with shale. A 72-hour pump test revealed dewatering throughout the "shallow aquifer." The water level in a test well 11 feet (3.4 m) away lowered by 7.54 feet (2.3 m); in a test well 205 feet (62.5 m) away, it lowered by 5.77 feet (1.8 m); and in a farm well 471 feet (143.6 m) away, it lowered by 5.39 feet (1.6 m).

The Wilson report noted that a wet area in the vicinity of Well 5 was spring-fed partly through old disused concrete cribbings. During a pump test, water flowing from two nearby concrete cribs was stopped completely, showing that water normally reaching these two spring discharge points was intersected by the well.

The report concluded that the aquifer was probably recharged from gravelly spillway deposits to the west, southwest, and possibly to the south of the well.

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[5] Initially referred to as Well 4, the well subsequently became Well 5.

It noted that these granular materials readily absorb precipitation, transporting it through the overburden, where it would reappear at the surface as springs or move downward to augment groundwater flow. The report noted: "Water moving through these friable deposits to the bedrock surface would enter the rock system in areas of fracture and weathering. Flow would then continue along these fracture or fissure zones. Well [5] intersected two of these zones at the test site."

As a result of these concerns, the Wilson report recommended that the pumping rate and pumping water level in Well 5 should be carefully monitored. The report cautioned that "if due to overpumping the water level approaches the upper water zone at 18 feet, the rate should be reduced or the well rested until the level resumes a safe depth." This was never made a condition of operation.

Bacteriological samples taken during the pump test indicated that bacterial contamination entered Well 5 between 12 and 24 hours after the start of the pump test (see Table 1).

Table 1 Walkerton Well 5, Pump Test Results, 1978

Time After Pumping Started	Total Coliforms/100 mL	Fecal Coliforms/100 mL
12 hours	0	0
24 hours	4	2
36 hours	8	0
48 hours	12	12
60 hours	8	6
72 hours	2	2
72 hours[6]	0	0

The presence of total and fecal coliforms in the water raised concerns about contamination from the surface and led to recommendations that consideration be given to controlling land uses in the immediate area. There was nothing done in this regard.

[6] The results of this sampling "are difficult to explain," according to the Wilson report, since it is a duplicate of the preceding sampling.

The nitrate content of the water (up to 5.0 mg/L) was within the MOE's permissible criterion of 10 mg/L for nitrate measured as nitrogen, but was still somewhat elevated. Nitrate is an oxidized form of nitrogen, whose most common source in water is chemical fertilizers; it may also result from organic (human and animal) waste. Nitrates are highly water soluble, so they cannot be filtered and do not degrade in groundwater. Unlike bacteria, nitrates do not die off. Once they enter an aquifer, they persist in the groundwater. Nitrates are often a sign of agricultural activities influencing a groundwater source.

In Chapter 9 of this report, I describe in detail the process that was followed at the time Well 5 was approved by the MOE. It is sufficient for present purposes to note that the Certificate of Approval issued on January 22, 1979 contained no operating conditions.

4.3.2 Early Bacteriological and Chemical Results

During the period 1978–80, two MOE environmental officers conducted a number of inspections of Well 5. These inspections clearly revealed concerns about surface water influence on Well 5 and the potential for the well's contamination. These concerns were based on the proximity of agricultural uses, the shallow well with a shallow overburden, fluctuating turbidity, microbiological test results showing fecal coliform contamination, and changes in spring water pumping levels. At the time, however, no steps were taken to either implement more stringent analytical or testing requirements, or to make revisions to the well's Certificate of Approval. During the 1980s, when the MOE did not conduct any inspections of this water system, these early inspectors' concerns were lost to time.

The first inspections of the new Well 5 were conducted on several occasions in 1978 and 1979. The inspector's report noted that the water level in Well 5 in March 1979 rose to between 3 feet (0.9 m) and 4 feet (1.2 m) below ground level, later dropping continuously to a depth of approximately 11.5 feet (3.5 m). The inspector concluded: "This increase in the pumping level coincided generally with the spring thaw and period of rain. This appears to confirm the relatively direct communication between this aquifer and the surface." The inspector recommended that Well 5 be monitored regularly to ensure that the parameters such as nitrates, total organic carbon, and phenols, which indicated contamination originating from the surface, did not increase beyond acceptable levels. He also noted that it had been recommended that the Town of Walkerton endeavour to exercise some control over surface activities in the area to the south and west of Well 5, and that any efforts to control land use activities in this area should be continued.

Several routine inspections of the PUC works were carried out during the period of June 1979–October 1980, approximately a year and a half after Well 5 was put in service. The inspector concluded that Well 5 was a shallow-drilled well susceptible to influence from surface activities due to the shallow overburden protecting the aquifer. His inspection report records raw water contamination by coliforms and fecal coliforms. In 1979, both coliform and fecal coliform counts were as high as 32 organisms per 100 mL. In 1980, of the 42 samples taken, four were adverse. The highest bacterial density was 260 total coliforms and 230 fecal coliforms per 100 mL. This water was seriously contaminated: these levels of fecal coliform contamination should not be found in a secure groundwater source. None of the treated water samples was of adverse quality. The inspection report concluded:

> The bacteriological quality of Well 5 reveals a variable bacteria density in the raw water throughout the year. The variation in the 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 turbidity results were also significant. The first report, in 1979, recorded that turbidity in Well 5 had been tested on nine occasions and that turbidity ranged from 0.10 to 0.54 formazin units (roughly equivalent to nephelometric turbidity units, or NTU). At no point did turbidity exceed the maximum acceptable concentration limit of 1.0 NTU as stipulated in the February 1978 version of the Ontario Drinking Water Objectives (ODWO). These turbidity results must be contrasted with the results recorded in the second report. Ten turbidity samples were taken between March 1979 and September 1980. Turbidity ranged from 0.15 NTU to 3.5 NTU; it exceeded the maximum acceptable level stipulated in the ODWO on two occasions (3.5 NTU and 1.8 NTU) and was at the maximum acceptable concentration of 1.0 NTU on one occasion. This degree of fluctuation of turbidity and such peak concentrations would not be expected in a secure groundwater source.

In the period 1978–80, the two inspectors both recognized the potential for the contamination of Well 5 based on various factors: the shallow overburden, the proximity of agricultural uses, fluctuating turbidity, microbiological test results showing fecal coliforms, and the changes in spring water pumping levels. I find that both the fecal coliform results and fluctuating turbidity, particularly in light of concerns raised by the Wilson report at the time of the well's construction, should have prompted further investigations by the MOE. Indeed, a former MOE approvals engineer testified that the fluctuations in turbidity and the level of nitrates set out in the second report, combined with raw water results from Well 5 indicating significant fecal contamination, were a cause for concern and indicated potential surface water influence. He remarked that if this kind of information had been received by him as a result of a monitoring condition in a Certificate of Approval, he would have directed either a hydrogeological or an engineering investigation to determine whether there was direct surface water influence and whether a continuous chlorine monitor should be required.

Indeed, after the May 2000 outbreak, a hydrogeological investigation undertaken by Golder Associates Ltd., discussed below, concluded there was direct surface water influence on Well 5.

4.3.3 Bacteriological Sampling Results: Wells 5, 6, and 7 and the Distribution System, 1990–2000

In this section, I review historical bacteriological sampling results from January 1990 to April 2000.[7] I conclude that the quality of water from Well 5, raw and treated, deteriorated during that decade.

The data are not entirely reliable. This is in part due to an improper practice of the Walkerton PUC operators to occasionally take samples at convenient locations other than those printed on the sample bottles and sample submission forms. A significant number of samples were taken at the tap in the Walkerton PUC shop that might have been labelled as either well samples or distribution system samples. Other samples taken at the wells were labelled as having come from some place in the distribution system. I refer to these practices elsewhere in this report as mislabelling sample bottles or locations.

The reliability of the bacteriological sampling result is also affected by the fact that water drawn from the tap at the PUC workshop is only a few minutes'

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[7] No records are available for the period October 1980–June 1990.

travelling distance from the chlorine injection point at Well 5. Therefore, this water did not receive the 15 minutes of chlorine contact time required for complete disinfection. As a result, these samples tend to reflect the water quality at Well 5. The importance of this fact is that the number of adverse samples from Well 5 may have been higher than was recorded and, correspondingly, the number of adverse samples from the distribution system and from Wells 6 and 7 may have been lower than was recorded.

Although I am not able to rely on the stated location of any sample as properly indicating the sample's source among the three wells, I am satisfied that the bacteriological results demonstrate that Well 5 had a significant coliform detection rate in the raw and treated water. The presence of coliforms in treated water indicates inadequate disinfection because these bacteria are very vulnerable to proper chlorination.

The Bruce-Grey-Owen Sound Health Unit kept track of all sample results during the period when the Palmerston Public Health Laboratory was testing the Walkerton water (January 1990 to September 1996). The results appear in Table 2.

The Ministry of Health's Palmerston Public Health Laboratory stopped testing Walkerton's municipal water in September 1996, when the ministry's public health laboratories withdrew from municipal water testing as part of the government's policy to privatize that activity.

From September 1996 to April 2000, bacteriological testing was performed by G.A.P. EnviroMicrobial Services Inc. under the direction of Garry Palmateer. He prepared a summary of coliform and *E. coli* detections in the Walkerton distribution system water from October 1996 to April 2000 (see Table 3).

Mr. Palmateer testified that in his experience (as well as that of the Ministry of Health's Central Public Health Laboratory in Etobicoke) the expected background level of total coliforms detection in a distribution system was approximately 4% and, for *E. coli*, less than 1%. This includes the level of total coliforms one would expect to find in a distribution system due to biofilm growth, and takes into account sampling errors for *E. coli*.

Tables 2 and 3 indicate that the quality of Well 5 water, both raw and treated, appears to have been deteriorating over the decade. Coliform detection in Well 5 raw water went from approximately 2.6% in the Palmerston laboratory

Table 2 Walkerton Water Microbiological Sample Results Provided by Palmerston Public Health Laboratory, January 1990–September 1996

Sampling Location[8]	Number of Samples	Total Coliforms		*E. coli*	
		Positive Samples	Percentage	Positive Samples	Percentage
Well 5 raw	349	9	2.6%	1	0.3%
Well 5 treated	351	7	2.0%	1	0.3%
Well 6 raw	10	2	20.0%	0	0%
Well 6 treated	29	1	3.4%	0	0%
Well 7 raw	335	12	3.6%	2	0.6%
Well 7 treated	335	18	5.4%	5	1.5%
Distribution system	1,234	33	2.7%	6	0.5%
Total	**2,643**	**82**	**3.1%**	**15**	**0.6%**

Table 3 Walkerton Water Microbiological Sample Results Provided by G.A.P. EnviroMicrobial Services Inc., October 1996–April 2000

Sampling Location[9]	Number of Samples	Total Coliforms		*E. coli*	
		Positive Samples	Percentage	Positive Samples	Percentage
Well 5 raw	116	13%	11%		<1%
Well 5 treated	115	8%	7%	1	<1%
Well 6 raw	25	3%	12%	0	0%
Well 6 treated	24	1%	4%	0	0%
Well 7 raw	98	3%	3%	0	0%
Well 7 treated	99	1%	1%	0	0%
Distribution system	471	12%	3%	4	<1%
Total	**948**	**41%**	**4%**	**6**	**<1%**

[8] Sampling locations may be incorrectly identified.
[9] Sampling locations may be incorrectly identified.

period to 11% in the G.A.P. laboratory period. Well 5 treated water coliform detection went from 2.0% in the Palmerston laboratory period to 7% in the G.A.P. laboratory period. Well 6 appears to have been undersampled in comparison with the other wells. Well 6 raw water had the highest coliform detection rate (20% in the Palmerston laboratory raw water tests and 12% in the G.A.P. laboratory raw water tests). Well 7 treated water positive samples declined from 5.4% in the Palmerston laboratory period to 1% in the G.A.P. laboratory period. The *E. coli* results all fall within the normal background rate of 1% or less. I will discuss the bacteriological samples taken immediately before and after the May outbreak in section 4.7.

4.3.4 Geology and Hydrogeology

Both geology and hydrogeology are crucial factors in understanding why the contamination in May 2000 was able to enter Well 5.

Geology refers to the study of rocks and the solid parts of the earth, and hydrogeology involves the study of the occurrence, movement, and quality of water beneath the earth's surface. The geology of the area around Well 5 involved a bedrock highly susceptible to fracturing. Well 5 drew its water from a shallow, highly fractured rock zone. The overburden – the area between the top of the bedrock and the surface – was very shallow. The significance of these geological factors is that a point source breach in the overburden could be connected to a fractured channel linked to the aquifer. This could lead to minimal natural filtration and a swift transport of living bacteria directly into the aquifer.

The hydrogeological features of significance here include the speed at which water will flow in such a highly fractured rock environment. They also include the presence of springs near Well 5 that stopped flowing when the well pump was operated and drew surface water into the well.[10] Tracer testing conducted after the tragedy revealed that surface tracer materials placed in those springs were transported into the well within a few hours after the well was turned on. These springs provide another route by which contaminated surface water could swiftly transport living bacteria into the well.

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[10] It is not known whether this also occurred when the well pump was not operated.

Well 5 is located near the southwest limit of the former Town of Walkerton, near the end of Wallace Street. It was constructed in 1978 to a total depth of 15 m. The overburden (the depth from the surface to bedrock) is 2.5 m. The bedrock surrounding Well 5 is composed of limestone and dolomite carbonate rocks that are susceptible to dissolution and fracturing. The upper portion of the bedrock below the overburden is a very permeable, highly porous, fractured rock material, extending approximately 7.5 m. The casing of Well 5 extends to only 5 m below the surface. All of the water entering Well 5 comes from a shallow zones ranging from 5.5 to 7.4 m below the surface.

Well 5 was equipped to be capable of pumping approximately 20.5 L/second or 1,771 m^3/day. This is just over 55% of the average daily flow required by the Town of Walkerton. Farm fields that are fertilized with manure lie to the west of Well 5. To the immediate north and east of Well 5 is a low, wet area that receives discharge from one or two springs.

All underground aquifers are replenished by surface water. In a secure groundwater source, however, surface water infiltrates through the overburden (generally a variety of soils, sand, silt, or clay) and again through bedrock. Such natural filtration will often take years. Since bacteria such as *E. coli* O157:H7 will live in water for weeks or months, and in soil for six months or longer, they are expected to be physically removed from the water flow and to die during this natural filtration process. In a secure groundwater source, there is no *direct* influence of surface water bacterial contamination on the groundwater source. However, certain factors may influence the effectiveness of the filtration process, such as a relatively direct connection between surface water and the aquifer. Where there is a direct connection between a well or aquifer and surface water, living bacteria may directly enter the groundwater source well.

4.3.5 Points of Entry

The area around Well 5 has a number of potential surface connections that were possible means by which contamination entered the well in May 2000. Among these are point source breaches in the area's overburden, which allow the rapid transport of water through the bedrock. Examples of possible point source breaches include fence post holes on the nearby farm, sand or gravel lenses, and improperly abandoned wells. Almost all of the water entering Well 5 comes from a highly fractured and weathered zone of bedrock. Well 5's casing ends within this zone, which is riddled with a finely scaled network of fractures in direct hydraulic connection with the overburden. Therefore, if contaminants breached the overburden, they would enter the fracture network and be carried to Well 5 in a short time.

Springs near Well 5 are another possible point of entry to the aquifer. There are two springs within 30 m of Well 5: one on the north and the other on the south side of the access road near Well 5. These springs have been observed to stop flowing when Well 5 is being pumped. During the flow distribution profiling conducted by Golder Associates Ltd.[11] on June 15, 2000, the spring north of the access road stopped flowing, water lying on the surface of the ground around the spring flowed back down into the ground, and within an hour, turbid water entered the well. This phenomenon is known as a "reversing spring": the spring flows normally from the ground, then reverses and flows into the ground.

On September 19, 2000, a tracer test was conducted on this spring by Golder Associates. Tracer materials were injected in the vicinity of the north spring. and Well 5 was operated. The tracer test confirmed a direct surface water connection at Well 5 through the north spring. Tracer materials were detected in the water from Well 5 within 60 minutes (electrical conductivity from sodium chloride) and within 77 minutes (sodium fluorescein, a green fluorescent dye) of their introduction in the vicinity of the north spring near Well 5. The sodium fluorescein was also observed to appear in the south ditch, near the well, where the south spring discharges, while the south spring continued to flow. Therefore, it is possible that surface water contaminated by bacteria may have entered Well 5 through the north spring in May 2000.

Dr. Stephen Worthington, a hydrogeologist called by the Concerned Walkerton Citizens, also conducted tests focusing on the connection between Well 5 and the north and south springs. He agreed with Golder Associates that the north spring may in certain conditions be a reversing spring, allowing surface water to flow into the aquifer from which Well 5 draws water. When he conducted a pump test, the springs on the north side of the road reversed in response to the pumping.

[11] Golder Associates Ltd. prepared a report for the Municipality of Brockton after the outbreak. The report is discussed in more detail below.

Dr. Worthington also observed the springs following a heavy (70 mm) rainfall on June 22, 2001. The daily average discharge at the springs was 10 L/second to 20 L/second. Following this rainfall the discharge increased to 30 L/second. He concluded that at times of heavy rain, particularly in spring, the flow from the springs is more than Well 5 can pump. He also found that the catchment area for the springs goes across the field where the manure – which I conclude was the source of the contamination – was applied. This provides a link between the springs near Well 5 and the source of contamination. However, in his view, the discharge of the springs near Well 5 was probably greater than the pumping rate of Well 5 around May 12, 2000. This makes it unlikely that the pumping of Well 5 drew local surface water into the springs and then into the well in May 2000.[12]

I also note that in a report dated November 23, 2000, Dr. Worthington concluded, on the basis of further fluorescein tracer tests, that surface water from Silver Creek (see Figure 1 on page 127) travels rapidly to the springs near Well 5. However, I am not able to conclude whether this is the case. The results from these tests were equivocal. Dr. Worthington did no background fluorescein analysis, and the small peaks detected were consistent with periods of rain that could have flushed background concentrations from surface pollutants into the groundwater.

In either event, I note that the geological and hydrogeological features of the area increased the risk of contamination entry to the aquifer. Water flow through fractured limestone and dolomite channels may increase dramatically, both in terms of distance and speed. Fracture zones within the bedrock may have a low porosity that permits a very high velocity of water, and water (with contaminants) may enter an aquifer many kilometres from the well itself. Where a relatively direct connection exists between the surface and a fractured channel, living bacteria may flow into an aquifer because of the speed at which surface bacteria are introduced into the aquifer by flowing through these fractures. This is in contrast to the more normal steady infiltration through overburden and bedrock, during which the bacteria are naturally filtered and die off. Direct connections through features such as springs may also lead to the entry of bacteria.

[12] I tend to agree with Dr. Worthington's conclusion in this regard.

4.3.6 Groundwater Under the Direct Influence of Surface Water

Because groundwater under the direct influence of surface water is vulnerable to contamination, additional treatment and monitoring steps need to be taken to ensure the safety of drinking water. I am satisfied that Well 5 was a groundwater source under the direct influence of surface water.

When Well 5 was approved in 1978, the 1973 version of the Chlorination Bulletin was in effect. Although the bulletin did not use the phrase "groundwater under the direct influence of surface water," it used a similar concept, providing that continuous and adequate chlorination be used when "groundwater sources are or may become contaminated, as in fractured limestone areas."

Because of concerns in 1978 that Well 5 was a groundwater source that might become contaminated, the MOE recommended that the water from Well 5 be treated with chlorine and that a chlorine residual of 0.5 mg/L after 15 minutes of contact time be maintained. The prevailing practice was to make recommendations for matters of this nature, not to include them as conditions in a Certificate of Approval.

In 1994, the ODWO were amended to include the concept of "groundwater under the direct influence of surface water." This amendment was modelled on the U.S. Environmental Protection Agency's Surface Water Treatment Rule. One of the purposes of the 1994 amendment was to require continuous chlorine monitors for groundwater sources that were found to be under the direct influence of surface water.

The MOE did not, however, publish any technical bulletins or guidelines listing factors that would indicate when a groundwater source was considered to be under the direct influence of surface water. For the purposes of my analysis, I have reviewed four sources of information that may indicate direct surface water influence on a groundwater source:

- **Biological Indicators** – The key biological indicators are fecal bacteria, including *E. coli*, in raw water. Given the relatively short lifespan of these organisms, the presence of fecal bacteria in a groundwater source indicates the presence of a source of fecal contamination, a short travel time from the surface, and a lack of adequate natural filtration by subsurface materials surrounding a well intake screen. Other biological indicators of surface water influence include algae, aerobic sporeformers, *Giardia*, *Cryptosporidium*, and human enteric viruses. The latter three pathogens would also indicate a fecal contamination source, but they are not normally monitored.

- **Physical and Chemical Indicators** – A fluctuation of turbidity is not expected in a secure groundwater source. Generally, turbidity should be relatively low (i.e., less than 1 NTU) and should not fluctuate considerably. Fluctuations in chemical parameters such as organic nitrogen or nitrates, total organic carbon and pH, or the physical parameter of electrical conductivity, may also indicate surface water influence. None of these chemical or physical parameters is uniquely indicative of fecal contamination.

- **Hydrological and Hydrogeological Indicators** – Any interaction between surface water features (e.g., springs, ponds) and wells may indicate that surface water is directly entering the aquifer from which the well draws water. Fracturing of the bedrock, thinness of overburden, point source breaches, and improperly abandoned wells may contribute to the entry of surface water.

- **Well Construction Indicators** – Holes in the well casing, improperly maintained backflow valves, and other aspects of well construction may provide a direct route for surface water entry.

Using these four indicators, I am satisfied that Well 5 was a groundwater source under the direct influence of surface water. The 1978 Wilson report, the early MOE inspection reports, and microbiological tests taken in the 1990s revealed the presence of *E. coli* in water samples from Well 5.

Physical and chemical tests also pointed to surface water influence. The fluctuating turbidity results in the 1980 inspection report were significant. As a rule, turbidity does not fluctuate in secure groundwater sources. The 1979 inspection report noted that an increase in the water level in Well 5 generally coincided with the spring thaws and rains, which the inspector said confirmed the relatively direct communication between the aquifer and the surface. The 1978 Wilson report noted that a pump test interrupted the flow of nearby springs. Both inspectors in 1979 and 1980 raised concerns about the influence of surface water. Finally, Well 5 was a shallow well with the casing extending only 5 m below the surface. All of the water-bearing zones were also very shallow and in an area of highly fractured bedrock.

In 1994, the ODWO were amended to provide extra monitoring for wells supplied by groundwater sources under the direct influence of surface water operating without filtration. Section 4.2.1.1 of the ODWO provided for continuous chlorine residual monitoring and turbidity monitoring by taking four grab samples a day or by continuous monitoring. For simplicity, I refer to this as continuous turbidity monitoring.[13] After the amendment, the MOE did not institute a program to reclassify existing wells.

I am satisfied that had the MOE instituted a program of reclassification after 1994, the information in its files was sufficient to show that Well 5 was under the direct influence of surface water. At a minimum, there was sufficient information to trigger an investigation that would have certainly revealed that situation. After 1994, the evidence that Well 5 came within this classification increased as the years passed. *E. coli* continued to show up in bacterial samples taken from the well. Between November 1995 and February 1998, there were five separate occurrences of adverse results, including *E. coli*. Still no steps were taken to reclassify Well 5, and, as a result, the MOE did not require the Walkerton PUC to install a continuous chlorine residual and turbidity monitors.

Had Well 5 been so classified, and had the requisite monitoring equipment been installed, the contamination entering the well in May 2000 would have been identified, and appropriate alarms could have shut down the pump. Continuous monitors would have prevented the outbreak.

An important purpose of installing continuous monitors is to prevent contamination from entering the distribution system. In reaching the conclusion that continuous monitors would have prevented the Walkerton outbreak, I am assuming that the MOE would have required that any such monitors be properly designed for the circumstances at Well 5. The monitors would thus have included an alarm as well as, in all probability, an automatic shut-off mechanism, because Well 5 was not staffed 24 hours a day and because the town had alternative water supplies –Wells 6 and 7.

Some might suggest that the operators of the Walkerton system would not have operated these monitors properly. However, if the MOE – which would have been responsible for approving the installation of these monitors – had any doubt that monitors would be operated properly, the obvious step would

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[13] As a practical matter, a continuous turbidity monitor, which costs only about $8,000, makes more sense than taking four samples a day.

have been to require an automatic shut-off device or alternative fail-safe mechanism. A shut-off mechanism would have involved only minimal additional expense.

In Chapter 5 of this report, I reject the suggestion that the PUC operators would have turned the pump at Well 5 back on if it had been automatically shut off. For the same reasons, I also reject any suggestion that the PUC operators, even if properly trained about the importance of continuous monitors, would not have responded appropriately to an alarm signalling that contamination was about to enter the distribution system.

4.4 The Source of Contamination

4.4.1 The Area Surrounding Well 5

Another important element in determining the cause of the contamination in May 2000 is identifying a source of contamination. I am satisfied that the primary, if not the only, source was the manure application in April 2000 on the Biesenthal farm near Well 5. In this section I set out a description of the farming and manure storage and application practices used on that farm. As discussed in the epidemiological evidence below, cattle from the Biesenthal farm were found by "DNA" typing to have the same strain of both *E. coli* O157:H7 and *Campylobacter* as the predominant human outbreak strain in Walkerton in May 2000. I am satisfied as to the strength of the link between this possible source, the location of the farm and Well 5, and the outbreak of illness and death in Walkerton.

In the spring of 2000, Dr. David Biesenthal was operating a cow calf operation on land near Well 5, on Lots 18 to 21 on the concession south of Durham Road. Figure 1, an aerial photo taken on September 9, 2000, shows the farm and Well 5.

The farmhouse can be seen in Figure 1. The barn is to the east of the farmhouse. A small paddock surrounds the barn on two sides. There is a fence around the paddock area where the manure storage pad was located, and another fence around the yard. The fence post holes around the paddock were dug by backhoe, to a depth of about 1.25 m. The fence post holes were approximately 2.4 m apart. The overburden was likely 2.5 m to 4 m deep, so the fence post holes penetrated a significant portion of the overburden.

Figure 1 Aerial View of Biesenthal Farm, September 9, 2000

Photo: Marc Bolduc, RCMP

Dr. Biesenthal farmed a total of 133 acres (54 ha). As can be seen in Figure 1, Lot 18 borders the west bank of Silver Creek. In 2000, it was the main area used for grazing. Lot 19 borders the east bank of Silver Creek and was used for grain crops and cut forage. These two lots drain toward Silver Creek. Lot 20 was used for grain crop production and contains the livestock barn and yard. There is also a small paddock used for calving and grazing for a brood mare; Lot 20 also provided some cut forage. Lot 21 was used for cut forage. The land and buildings on Lot 21 are the Gutscher property, formerly the Pletsch property. Dr. Biesenthal took forage from Lot 21 but did not own the land. Most of the natural drainage from Lots 20 and 21 is to the east, presumably feeding the spring and wetland close to Well 5. The soil is loam. The depth to bedrock on Lots 20 and 21 ranges from 1.5 m to 7 m.

4.4.2 Animal Husbandry and Manure

In 1999–2000, Dr. Biesenthal maintained a breeding herd of about 40 Limousin cows and heifers. The cows calve mainly in the barn from December to April. Animals from other operations are brought onto the farm in late April or early May and are sold off in the fall, together with calves from the previous winter. A maximum of 95 head of cattle may be on the farm during the spring and summer.

During the late fall and winter, the cattle are confined to the barn, the associated concrete apron, and the small paddock that surrounds the barn on two sides. In the spring, the animals are put out to the main pasture in the field to the west of Silver Creek but are allowed access to the barn to drink. Silver Creek has been fenced off and bridged to prevent animals from defecating into the stream.

On the Biesenthal farm, the manure is "solid manure." The animals are provided with straw bedding; this is typical of many beef and dairy operations. The cattle's feces and urine are mixed with the straw to form a solid manure with about 19% dry matter. In Ontario, the proportion of dry matter in solid beef-cattle manure ranges from 18% to 63%.

Manure is typically applied to the farm fields as fertilizer in the late fall before freeze-up and in the spring before planting. In November 1999, the Biesenthals applied all the manure they had in storage – approximately 105 tons[14] – to the field on Lot 20 north of the barn and paddock. The application rate was approximately 12 tons/ha. Manure was incorporated into the soil within 24 hours after application by using a disc harrow. The depth of incorporation was approximately 7 cm.

Manure accumulated from November through April was stored on an open concrete pad in the paddock area. There was no runoff system to collect feces or urine. The farmer used a tractor scraper to transfer manure from the barn and the yard onto the concrete pad. The concrete pad was able to hold approximately 200 days' manure production.

A significant rainfall occurred on April 20–21, 2000. On April 22, approximately 24 hours later, 70 tons of manure stored on the concrete pad were

[14] The system of measurement (Imperial, U.S., or metric) was not specifically identified.

removed and spread on the east front field of Lot 20. Again, the application rate was approximately 12 tons/ha. Within 24 hours, manure was incorporated into the top 7 cm of soil using a disc harrow. About 73 tons of manure were exported to another farm.

The application rate of 12 tons of manure per hectare represents approximately 120 g fresh weight per square metre, which is less than 25 g dry weight per square metre. Fresh manure can contain between 10^6 to 10^9 fecal coliforms per gram dry weight. Although few of the organisms would move below the cultivation depth, and in the weeks after the application many would have died, a significant source of fecal coliforms was applied and incorporated into the soil near Well 5 on April 22. At its closest point, manure was applied 81 m from Well 5.

It is important to note that Dr. Biesenthal's manure handling, storage, and spreading practices were consistent with what are considered "best management practices" by the Ontario Ministry of Agriculture, Food and Rural Affairs. Therefore, although it is virtually certain that the contamination that caused the outbreak originated on his farm, Dr. Biesenthal cannot be faulted.

4.4.3 The Lifespan of *E. coli* O157:H7 in Soil

Studies done on the survival of *E. coli* O157:H7 in various soil types indicate survival times of at least 10 to 25 weeks. Dr. Michael Goss, chair of the University of Guelph's land stewardship program, and Dr. Pierre Payment, an environmental microbiologist specializing in waterborne pathogens and a member of the Walkerton Commission's Expert Review Panel, agreed that for loam soil, studies have demonstrated the survival of *E. coli* O157:H7 at 25 weeks. Further, cooler soil temperatures tend to promote longer survival times.

Dr. Goss testified that *E. coli* will survive longer when they are infiltrated into the soil because they are not subject to drying or ultraviolet light, as they are when at or near the surface. The manure applied on April 22 was incorporated into the soil within 24 hours of spreading. As a result, by May 12, most of the bacteria in this incorporated manure were still likely to be viable, except those exposed at the soil surface. Rain prior to May 12 would be expected to infiltrate the soil, thereby encouraging the movement of bacteria close to the soil surface into the deeper layers, where their viability is enhanced. In these circumstances, *E. coli* in the front east field could survive for up to 6 months.

4.5 Wells Supplying the System in May

In seeking to determine the cause of the contamination, I have considered which wells were pumping and thereby supplying water to the distribution system during the relevant times. Through the critical period of May 10 to May 15, Well 5 was the primary well, providing most of the water to the distribution system.

Discrepancies exist between the manually prepared daily operating sheets for Well 7 and the electronic Supervisory Control and Data Acquisition (SCADA) system records. These discrepancies relate to the days on which Well 7 was operated, as well as to the volumes pumped. The SCADA system generates electronic records of pump operating times and water volume. I do not rely upon the Well 7 daily operating sheet for the month of May 2000. The daily operating sheet for Well 7 for May was rewritten on May 22 or May 23. It is not accurate. For example, the daily operating sheet shows that no wells were operating within Walkerton's water system during the period from May 3 through May 9. This is impossible, because the water system has, at most, two days' storage capacity.

I am satisfied that the electronic SCADA records more accurately depict when the wells were operating than do the daily operating sheets.[15] The SCADA information shows reasonable and consistent pumpage cycling and pumpage values. In the result, I find that:

- Well 7 did not operate from March 10 to May 2, 2000. Well 7 was the only well supplying the system from May 2 at 7:45 a.m. to May 9 at 1:45 a.m.
- Well 5 operated continuously from May 9 at 9:15 a.m. to May 12 at 10:45 p.m. It started again May 13 at 2:15 p.m. and ran continuously until May 15 at 1:15 p.m. It was off until May 20 at 10:45 a.m.
- Well 6 cycled on and off between May 9 at 6 p.m. and May 13 at 5 p.m. There is no data for some times before and after that period, but it seems unlikely that Well 6 was turned on again after May 13 at 6 p.m.

[15] I note that the SCADA data for Well 6 are incomplete, partly because of a power failure on the weekend of May 13–14.

- Well 7 was turned on again on May 15 at 6:15 a.m. and operated until May 19 at 10:30 a.m.

The chlorinator at Well 7 was removed before noon on May 3, and the new chlorinator was not installed until May 19. Therefore, unchlorinated water was supplied to the distribution system through Well 7 from May 3 at noon until May 9 at 1:45 a.m., and again from May 15 at 6:15 a.m. until May 19 at 10:30 a.m. The evidence is that the new chlorinator was installed by noon on May 19.

As I conclude below, the epidemiological and other evidence indicates that the water supply likely became contaminated on or shortly after May 12. Well 5 was the primary source of water from May 9 to the early morning of May 15. Well 6 was the secondary source during this period. Well 7 was not in operation during this key period; it was turned on again at 6:15 a.m. on May 15 and operated without chlorination until shortly before noon on May 19. I am satisfied that the exposure to the infection started some time before Well 7 was turned on and that there must have been another source of the contamination.

The volume of water pumped into the system is also important. As can be seen in Table 4, Well 7 provided most of Walkerton's water from May 3 to 9. However, Well 5 was providing the majority of the water to the distribution system from May 10 to 15, which I find to include the crucial contamination period.

Table 4 Summary of Well Flow, May 2000: Volume Pumped (m^3)[16]

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	W	**T**	**F**	**S**	**S**	**M**	**T**	**W**	**T**	**F**	**S**	**S**	**M**	**T**	**W**
Well 5	12	12	12	12	14	11	12	1811	1725	1868	1181	1514	1530	418	12
Well 6[17]	7	7	7	7	7	7	NR	873	264	989	1104	NR	NR	NR	NR
Well 7	2249	2891	2809	2813	3288	3299	2914	17	3	10	12	14	548	2931	2470
Daily Total	**2268**	**2910**	**2828**	**2832**	**3309**	**3317**	**2926**	**2701**	**1992**	**2867**	**2297**	**1528**	**2078**	**3349**	**2482**

[16] NR = not recorded.

[17] From May 3 to May 8 inclusive, May 10, and May 13, SCADA pumpage for Well 6 was calculated from midnight to midnight. The SCADA system did not properly record pumpage from Well 6 on May 9 or from May 14 to May 18 inclusive.

4.6 Rainfall

Environment Canada meteorologist Heather Auld testified with respect to the estimated rainfall in Walkerton in the April–May period. On April 20–21, 35.8 mm of rain fell in the Walkerton area. The cumulative total monthly rainfall for April was 50 mm. Rainfall estimates for early May appear in Table 5.

Table 5 Estimated Rainfall, Walkerton, May 1–12, 2000

Date	Rainfall (mm)	Cumulative Monthly Total (mm)
May 1	5.5	5.5
May 8	15.0	20.5
May 9	15.0	35.5
May 10	20.0	55.5
May 11	12.5	68.0
May 12	70.0	138.0

Environment Canada took into account the surface weather, radar results, real time measurements, and climate data to estimate the rainfall amounts for May 8 to May 12, 2000. Walkerton received 70 mm of rainfall on May 12. It also had significant rainfall in the preceding days, beginning on May 8. A total of about 134 mm of rain fell in Walkerton during the five-day period of May 8 to May 12.[18]

Meteorologists measure the significance of rainfalls by "return periods." A return period estimate is the average time interval between an event level. A 10-year return period for an event or storm would mean that an average of 10 such events could be expected to occur in a 100-year period. Ms. Auld estimated that the 134 mm rainfall for the five day period from May 8 to May 12 could be expected to recur, on average, once every 60 years for the month of May. It was clearly a significantly wet period. The May 12 rainfall by itself corresponded to a return period of less than 10 years. The record one-day rainfall for Walkerton, recorded in 1964, was 125 mm.

Most of this very heavy rain on May 12 fell between 6 p.m. and midnight. Environment Canada did not have records indicating the time of day at which

[18] Ms. Auld testified that between 130 and 140 mm of rain fell between May 8 and 12, and her "best guess" was 134 mm.

the rain fell, but a hydrology study completed several months later[19] concluded that approximately 60 mm fell between 6 p.m. and midnight, contributing to a total of 72.4 mm for the entire day of May 12. This is consistent with the Environment Canada daily estimate.

4.7 Adverse Samples

I find that the bacteriological samples taken both immediately before and after the May 2000 outbreak support the conclusion that Well 5 was the source of the contamination in May. The turbidity data is inconclusive.

4.7.1 April 2000 Sampling Results

The April 2000 results from the Walkerton water system indicate an emerging issue concerning water quality at Well 5.[20] On three of four April sample dates, Well 5 raw water tested positive for total coliforms. On April 3, Well 5 raw and treated water and two distribution system samples tested positive for coliforms, whereas coliforms were not detected in samples from Well 6 and two other distribution system samples. On April 11, coliforms were shown to be present in Well 5's raw water. A presumptive positive finding regarding one distribution system location was not confirmed on further testing. The remaining distribution samples and Well 6 samples did not contain coliforms. On April 17, both Well 5 raw and Well 5 treated water tested positive for total coliforms. But total coliforms were not detected in distribution system samples. Finally, on April 24, both Well 5 samples and the two distribution system samples were negative. There were no samples from Well 7 in April 2000 because that well was not operating from March 10 to May 2, 2000.

4.7.2 Early May Samples

Bacteriological samples taken on May 1 indicate that samples labelled "Well 5 raw" and "Well 5 treated" both tested positive for total coliforms and negative for *E. coli*. All other samples from May 1 were negative. The next samples were taken on May 8. Those samples were labelled "Well 7 raw," "Well 7 treated,"

[19] By Stantec Consulting Ltd., for B.M. Ross and Associates Ltd.
[20] These comments are of course subject to the mislabelling issue I discussed above.

"125 Durham Street," and "902 Yonge Street," respectively – the latter two being two locations in the distribution system. All these samples were negative for both total coliforms and *E. coli*.

4.7.3 May 15 PUC Sampling

Two sets of samples were taken on May 15. One set of three samples came from the Highway 9 construction project, which is discussed in the next section. The regular weekly samples submitted by the Walkerton PUC on May 15 included four samples from the Walkerton distribution system.

The May 15 sample apparently containing Well 7 raw water did not contain either total coliforms or *E. coli*. However, the samples apparently consisting of treated water from Well 7 and the two locations in the distribution system all came back positive for both total coliforms and *E. coli*. The membrane filtration result for the sample labelled "Well 7 treated" had total coliforms greater than 200 cfu/100 mL and *E. coli* of 200 cfu/100 mL.

Allan Buckle, an employee of the Walkerton PUC, testified that on May 15, Frank Koebel, the PUC's foreman, asked him to take samples from Well 7. Mr. Buckle went to Well 7, and when he arrived there, the well was running without a chlorinator.

Mr. Buckle testified that he arrived at Well 7 with four prelabelled sampling bottles: one for the raw tap, one for the treated tap, one for 125 Durham Street, and one for 902 Yonge Street. He said that he filled the sample bottle labelled "raw water" from the raw water tap at Well 7 and filled two sample bottles with water from the treated tap at Well 7. He stated that on his return to the PUC shop, he gave the remaining bottle labelled "902 Yonge Street" to Stan Koebel. I have concluded that Mr. Buckle erred in saying he took the samples at Well 7 and that it is most likely that Mr. Buckle took the three samples at the PUC shop, which is near and just down the line from Well 5.

It is clear that the locations shown on the three samples that Mr. Buckle says he took were, in fact, inaccurate. All of the experts agreed that it was inexplicable that total coliforms and *E. coli* could be absent in "raw water" at the same time that a sample of the "treated water" was grossly contaminated (total coliforms greater than 200 cfu/100 mL; *E. coli* 200 cfu/100 mL; heterotrophic plate count (HPC) 600 cfu/1 mL). Further, even according to Mr. Buckle, the sample he had labelled "125 Durham Street" was incorrect; he did not go to 125 Durham Street on May 15. In addition, since Well 7 was operating on May 15 without a chlorinator, it is most improbable that one sample from Well 7 would be negative while the other two were positive.

Moreover, Mr. Buckle testified that he regularly misrepresented the sites of samples. For example, on May 15, all the samples represented as having come from two small waterworks unconnected to the Walkerton water system were actually taken at the pumphouses for the sake of convenience. However, some were labelled as distribution system samples. The PUC shop was a more convenient location than was Well 7 for taking water samples for the Walkerton system.

Most importantly, the other evidence is overwhelming that Well 5 was contaminated but Well 7 was not. The logical conclusion is that these samples were taken from a location near Well 5, most probably at the PUC shop.[21] Indeed, Stan Koebel ventured that this was the case. He, as much as anyone, was aware of Mr. Buckle's practices when taking samples.

Accepting that the May 15 samples came from the PUC shop, it still remains to be explained how one of those samples was negative. There is no clear explanation, although one possibility arises from the fact that all service connections, like the PUC shop, are essentially dead ends. One possible explanation for the May 15 results (assuming that they came from the PUC shop) was that the PUC shop's tap had not been used over the May long weekend. The first sample taken may have been clear water that had been in the pipe before the May 12 storm. The remaining samples, even if they were taken at the same location, would contain contaminated water that entered the system after the storm. No one has suggested any other explanation.

4.7.4 May 15 Highway 9 Project Samples

All of the three samples taken from the hydrants on the Highway 9 new watermain project on May 15, 2000, tested positive for both total coliforms and *E. coli* in a presence-absence test. No numerical counts were taken.

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[21] It is also possible that Mr. Buckle took the samples at Well 5. For the purposes of my analysis, there is no difference.

Allan Buckle testified that on May 15 he received a call and was told to pick up four empty sample bottles and take them to the Highway 9 project. There he was to meet PUC general manager Stan Koebel and a representative of the contractor, Lavis Construction Ltd., at a hydrant they were flushing near the Ministry of Transportation shed at the intersection of Highway 9 and Wallace Street. Mr. Buckle testified that he took two of the bottles and filled them with water from a hose attached to the hydrant. He stated that the contractor also filled two bottles that Mr. Buckle believed were taken from another hydrant near the Energizer Canada plant, on Highway 9 east of the Ministry of Transportation shed.

Dennis Elliott of B.M. Ross and Associates Ltd., who was a site inspector for the Highway 9 construction, also testified with respect to the collection of bacteriological samples at the Highway 9 project. He stated that the collection of bacteriological samples from the flushed line containing water from the municipal water system began at 11:15 a.m. on May 15. Mr. Elliott testified that he and the contractor filled two sample bottles at the hydrant near the Ministry of Transportation shed at Wallace Street, and that a third sample bottle was filled from the easterly hydrant at the Energizer Canada plant. Mr. Elliott then took the three samples to the PUC office on Park Street, where they had earlier arranged to ship the samples out with the regular Monday samples. He had requested that the samples be marked “rush.”

I note that Mr. Elliott’s testimony is inconsistent with Mr. Buckle’s. Mr. Buckle testified that he took four bottles over to the construction site and that he himself filled two of those bottles while the contractor filled two other bottles. Testifying with the benefit of contemporaneously made notes, Mr. Elliott gave evidence that he, together with the contractor’s foreman, Wayne Greb, filled three bottles and that Mr. Elliott delivered those bottles to the PUC. On this point, I prefer Mr. Elliott’s evidence. Only three bottles were in fact forwarded to the laboratory for testing.

4.7.5 May 18 Highway 9 Samples

Because of the fact that samples taken on the Highway 9 project on May 15 were positive for total coliforms and *E. coli,* further samples were taken on May 18 and submitted to MDS Laboratory Services Inc. in London. Two samples were taken from the hydrant nearest the Ministry of Transportation shed at the intersection of Highway 9 and Wallace Street. One sample showed a concentration of total coliforms of 26 cfu/100 mL and *E. coli* at 9 cfu/100 mL. The other sample showed total coliforms of 43 cfu/100 mL and *E. coli* at 14 cfu/100 mL. The sample taken from the hydrant nearest the Energizer Canada plant recorded total coliforms of 78 cfu/100 mL and *E. coli* at 10 cfu/100 mL.

4.7.6 May 21–23 Samples

Stan Koebel began flushing and superchlorinating the distribution system on May 19. A significant number of samples were taken by the Bruce-Grey-Owen Sound Health Unit, the MOE, and the PUC in the period May 21 through May 23. Very significantly, all of the Well 5 raw water samples showed contamination by both total coliforms and *E. coli*. None of the samples from either Well 6 or Well 7 showed any total coliforms or *E. coli*. Finally, the only distribution system samples that showed either total coliforms or *E. coli* contamination were from two locations in the southwest area of town near Well 5, both of which were at dead ends of the water distribution system.

James Schmidt took samples from the distribution system for the health unit on May 21, May 22, and May 23; they were analyzed at the Ministry of Health laboratory in London. Of the 21 samples taken on May 21, only two were adverse. The Yonge Street and Highway 9 store sample had total coliforms of greater than 80 cfu/100 mL and *E. coli* at 69 cfu/100 mL. The sample from the Bruce County administration building had total coliforms of 2 cfu/100 mL and *E. coli* at 2 cfu/100 mL. The location of these two adverse samples is significant. Both were located in the southwest end of town and were closer to Well 5 than to either of the other two wells. More importantly, each of the locations was at a dead end in the system. The water flow would stagnate in the dead ends and, after contamination had been introduced, bacteria there would be less likely to be killed by flushing and increased chlorination.

On May 22, all of the distribution samples taken by the health unit tested negative except for the same two locations: the fast food outlet south of the intersection at Yonge Street and Highway 9, and the Bruce County administration building on Park Street. Concentrations of total coliforms of greater than 80 cfu/100 mL and *E. coli* of greater than 50 cfu/100 mL were found in the sample taken at the fast food outlet. For the sample taken at the Bruce County administration building, total coliforms were 20 cfu/100 mL and

E. coli were 10 cfu/100 mL. The only well tested was Well 7, and both the raw water and treated water samples were negative.

On May 22, John Earl from the MOE took samples that were tested at the ministry's central laboratory. Two samples were taken at 4 Park Street, one from the raw water at Well 7, and one from Well 7 treated water. All these samples tested negative.

On May 23, the MOE, the PUC, and the health unit took more water samples. The samples taken by the MOE of the raw water at Well 5 showed total coliforms in a concentration greater than 300 cfu/100 mL and *E. coli* at 100 cfu/100 mL. A sample of treated water taken from Well 5 showed concentrations of total coliforms greater than 300 cfu/100 mL and *E. coli* at 120 cfu/100 mL. The samples taken from the treated water at Well 6 and the raw water at Well 7 were clear on that day, as were the three distribution system samples.

On May 23, the PUC also took samples, which were tested by A&L Canada Laboratories. The Well 5 raw samples showed total coliforms greater than 200 cfu/100 mL and *E. coli* at 33 cfu/100 mL. Well 7 raw and treated samples were clear, as were the distribution system samples. Finally, on May 23, all the health unit distribution system samples were negative, except for the one from the fast food outlet and the Bruce County administration building. The results for the samples taken on May 23 at the fast food outlet were total coliforms of 17 cfu/100 mL and *E. coli* at 11 cfu/100 m1, while the Bruce County administration building showed readings of total coliforms 2 cfu/100 ml and *E. coli* 2 cfu/100 ml.

4.7.7 Soil and Water Samples Taken Near Well 5 After the Outbreak

Both soil and water samples taken near Well 5 after May 2000 revealed the presence of *E. coli*. Soil bacteriological results from 23 bore holes at 12 locations near Well 5 indicated the presence of significant total coliform bacteria above the detection limit in all bore holes except one, and *E. coli* in bacteria from five of the 23 bore holes. Near-surface samples in some of the bore holes had total coliform counts of 2,800 cfu/100 g, 1,000 cfu/100 g, 1,600 cfu/100 g, and 7,400 cfu/100g.[22] Elevated *E. coli* counts were also noted for the same samples, ranging from 70 cfu/100 g to 940 cfu/100 g. Mr. Palmateer's evidence was that typical surface and subsurface soil coliform populations can exceed 100,000 cells/100 g and 200,000 cells/100 g, respectively, so these results are not excessive. I note, however, that the *E. coli* levels in these samples near Well 5 were significantly higher than the levels in soil samples taken near Wells 6 and 7.

Particularly important are pump test results obtained by Golder Associates Ltd. from two monitoring wells located west-northwest of Well 5 in late August 2000. Monitoring Well 12D is located on the Biesenthal farm, near the paddock area, approximately 225 m west of Well 5. Monitoring Well 2D is located 105 m west-northwest of Well 5, in a grassy area adjacent to the woods.

E. coli results after a 32-hour pump test are shown in Table 6. The results indicate continuing high *E. coli* counts on the Biesenthal farm in late August 2000. They also demonstrate that as Well 5 pumped, *E. coli* levels increased in both of the monitoring wells and in Well 5, implying some hydrogeological connection between the farm and Well 5.

Table 6 *E. coli* Results After Pump Test (cfu/100 mL)

Monitoring Well 12D		Monitoring Well 2D	Well 5
Before pumping	>8,000	< 10	< 1
After pumping	12,000	900	20

Another significant result was a June 6, 2000, water sample taken from the spring adjacent to Well 5, which had a count of 80 *E. coli* cfu/100 mL. This indicates that *E. coli* persisted in a significant region around Well 5 for at least three weeks after the contamination and outbreak. Further, Dr. Robert Gillham testified that this spring discharges a few gallons per minute, and it does so continuously. In his view, this sample result from the spring indicates that a large area of bedrock near Well 5 must have been contaminated.

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[22] Bacterial counts generally decreased in deeper samples in these bore holes. It is important to note that bacterial levels in soil samples are expected to be much higher than they are in drinking water samples, particularly for total coliforms, which include natural soil bacteria, in contrast with *E. coli,* which are reliable indicators of fecal contamination.

4.7.8 DNA and Epidemiological Typing

The results of the DNA typing of animal and human samples are most persuasive. A clear link exists between the bacteria found in cattle manure on the Biesenthal farm near Well 5 and the human outbreak strains of *E. coli* O157:H7 and *Campylobacter*. I am satisfied that the primary, if not the only, source of the contamination was manure from this farm, although I cannot rule out other possible sources of contamination.

Dr. Andrew Simor is an infectious diseases specialist and head of the Department of Microbiology at the Sunnybrook and Women's College Health Sciences Centre in Toronto. An expert in molecular and epidemiological typing, he testified about the molecular and epidemiological typing methods used to classify pathogens found in human stools, animal fecal samples, and water samples during the Walkerton outbreak investigation. Polymerase chain reaction (PCR) testing of *E. coli* O157:H7 involves extracting the DNA from an organism and identifying verotoxin genes by enzyme immunoassay. PCR testing will confirm a verotoxin-positive *E. coli* O157:H7. Verotoxin-negative strains of *E. coli*, even *E. coli* O157:H7, will not cause human illness. PCR testing demonstrates whether *E. coli* O157:H7 is verotoxin-positive; it does not identify whether strains of the bacteria taken from different samples are related or derive from a common source.

Epidemiological typing is used to characterize organisms in order to determine if they represent the same strain, such as a common source in an outbreak.

Epidemiologically related isolates derived from a single precursor share common characteristics that differ from those of unrelated strains. There are hundreds, if not thousands, of *E. coli* O157:H7 strains that can cause human disease. To determine whether the same strain of *E. coli* O157:H7 is causing the disease, microbiologists resort to typing the organisms found in fecal and environmental samples. Three forms of epidemiological typing were used for that purpose in this investigation: phage-typing, serotyping, and pulsed-field gel electrophoresis (PFGE).

- Phage-typing involves characterizing isolates by their susceptibility or resistance to a variety of bacteriophages, which are viruses that can infect bacteria.

- Serotyping detects cell wall antigens; it is commonly used to type *Campylobacter*. Both phage-typing and serotyping involve looking at the properties of bacteria.

- Pulsed field gel electrophoresis (PFGE) is the gold-standard method of typing. PFGE involves looking at the molecular properties (the DNA) of the organism and is a type of “DNA fingerprinting.” In PFGE, enzymes are used to extract DNA fragments that are then separated by size on electrophoresis gel. This produces a particular DNA pattern. When PFGE results have the same pattern, the bacteria are of the same strain.

The epidemiological evidence of the link between the human outbreak strains of both *E. coli* O157:H7 and *Campylobacter* and those found on the Biesenthal farm persuades me that the source of these bacteria was the Biesenthal farm. Health Canada sampled potential animal reservoirs within a 4-km radius of the three municipal well sites, as well as testing deer droppings in the vicinity of the wells. All wildlife specimens were negative for *Campylobacter* and *E. coli* O157:H7. Of the 13 livestock farms tested, *Campylocbacter* bacteria were found on 11 of the farms. *E. coli* O157:H7 and *Campylobacter jejuni* were found on only two farms. One was the Biesenthal farm near Well 5, and another was a farm within a 4-km radius of Wells 6 and 7.

The Bruce-Grey-Owen Sound Health Unit report indicates that there were 174 confirmed stool samples of human *E. coli* O157:H7 infection. Of these, 94% were PFGE type A or A4, the same strains as were found in cattle and manure at the Biesenthal farm. In contrast, the PFGE pattern of the *E. coli* found in cattle on the other farm, within the 4-km radius of Wells 6 and 7, was PFGE type A1. There were only two human cases of PFGE type A1.

Importantly, while *Campylobacter coli* and *C. jejuni* were identified on both the Biesenthal farm and the other farm, only the phage types of the *Campylobacter* on the Biesenthal farm matched the predominant human outbreak strain (phage type 33), and the majority of these isolates had a similar surface antigenic profile upon serotyping to those seen in the human cases. The phage types of the *Campbylobacter* on the other farm did not match the human outbreak strains.

Since not all of the cattle on the farms were tested and the testing did not take place until June 13, there may have been other strains present on, for example, the Biesenthal farm that simply were not identified by the Health Canada team.

These findings show a reservoir of bacteria that match the human outbreak strain in the vicinity of Well 5 during the time frame of the outbreak. Although no samples were taken from the Biesenthal farm before the outbreak, Dr. Andrea Ellis[23] testified that it is reasonable to assume that these bacteria may have been present in early May or late April, given the ecology of *E. coli* on farms.[24]

The evidence of typing is very strong. Based on available PCR, phage-type, serotype, and PFGE results, I find that the *E. coli* O157:H7 and *Campylobacter* isolates from the vast majority of human patients and from the Biesenthal farm cattle and manure were genetically related and that the farm was likely the source of the vast majority, if not all, of the contamination.

4.7.9 Other Microbiological Evidence

Raw and treated water samples taken from Well 5 on May 23 demonstrated gross microbiological contamination, with total coliform concentration greater than 300 cfu/100 mL and *E. coli* at 102 cfu/100 mL. These samples were sent to the Ontario Ministry of Health and Long-Term Care (MOH) laboratory for PCR tests to look for the DNA specific to *E. coli* O157:H7 bacteria. The laboratory identified the verotoxin gene for *E. coli* O157:H7, indicating that this bacteria had been present in the water at Well 5. No *E. coli* O157:H7 bacteria were found in samples of Well 6 or Well 7 water taken near the time of the outbreak. Indeed, no confirmed *E. coli* O157:H7 were ever found in Well 6 or Well 7 samples.

There was one anomalous result of an environmental sample taken from a pipe at a pond near Well 6. G.A.P. EnviroMicrobial Services Inc. was retained by

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[23] Dr. Andrea Ellis is section head of the Outbreak Response and Issues Management, Division of Enteric, Food-borne and Water-borne Diseases, Population and Public Health Branch, Health Canada.

[24] In his report dated November 23, 2001, Dr. Stephen Worthington interpreted the health unit data and concluded that the evidence “strongly suggests” that the bacteriological contamination in May 2000 came from a number of different sources at a number of different farms. Dr. Ellis disagreed. She is an epidemiologist. As such, she noted that: “Had the contamination actually come from multiple wells and multiple farms then we would not expect to find almost 90% of the patients infected with the identical strain of E. coli O157.” She also noted the consistency of molecular sub-typing results across several different methods – PFGE, phage typing, and serotyping – a consistency not found on any of the other livestock farms tested in the area of the wells and a factor not considered by Dr. Worthington. I prefer the evidence of Dr. Ellis in this regard.

the Ontario Clean Water Agency to conduct an environmental investigation after the outbreak. There is an excavated pond about 100 m from Well 6. A plastic pipe connects this pond near Well 6 to another pond on private property, which in turn is fed by an artesian spring. A water sample taken from the pipe by Garry Palmateer of G.A.P. on June 8, 2000, was found to contain *E. coli* O157:H7. The MOH Central Public Health Laboratory confirmed that the PFGE results from the *E. coli* O157:H7 water sample were verotoxin-positive and matched the predominant human outbreak strain.

There is no obvious explanation for the presence of this strain of *E. coli* O157:H7 at that location on June 8. There are many possibilities: bacteria may have been transported by an animal or bird to the pipe, or an infected human may have shed the pathogen; ironically, it may also have been transported on the footwear of someone involved in investigating the cause of the outbreak. Apparently the pond is part of a decorative garden fertilized with compost. Further, it is partly fed by a domestic well, and the pipe drains water from the area of a private home and septic system. Whatever the explanation, this single result from that location on June 8, when lined up with the other available evidence, falls far short of suggesting that *E. coli* O157:H7 entered the distribution system through Well 6 during the May outbreak.

4.8 Expert Evidence

The experts who testified at the Inquiry all shared the view that Well 5 was the entry point for the contamination point into the system.[25] Their opinions were, in general, based on the factors I have discussed above. The remaining issue is the pathway the contamination followed in travelling to the intake for Well 5. Broadly stated, the issue is whether the contamination entered by surface flooding in the area surrounding the well or by subsurface transport to the aquifer. Although a definitive answer is not possible, it appears more likely that the contamination entered through the fractures or conduits through the bedrock and into the aquifer that fed Well 5, rather than by way of overland flow. However, I cannot rule out the latter or a combination of both. I will briefly review the expert evidence.

[25] In late November (after conducting further tests), Dr. Stephen Worthington stated that Well 6 and/or Well 7 could have been a secondary source of contamination. His opinion, however, goes no further than to state that Well 6 and to a lesser extent Well 7 may be susceptible to surface contamination. There is no evidence to support a conclusion that contamination in fact entered the system through Wells 6 and 7 in May 2000.

Dr. Robert Gillham is a professor of earth sciences and industrial research chair in groundwater remediation at the University of Waterloo. He is also a member of the Walkerton Commission Expert Review Panel. He testified that the evidence that Well 5 was the source of the contamination was "overwhelming." For him, the most compelling evidence was the hydrogeological conditions at the well and the depth of the well, the *E. coli* measured in both the well water and the spring near Well 5 in June (indicating the presence of a large body of groundwater in the vicinity containing *E. coli*), and the fact that an identifiable source of contamination existed within the groundwater catchment area of Well 5.

Conversely, the pumping schedule and conditions at Wells 6 and 7 made those wells an improbable source. Dr. Gillham testified that although Well 6 was vulnerable to surface contamination, that well was an improbable contributor to the May 2000 outbreak. On June 8, 2000, *E. coli* O157:H7 was identified in a single sample – from the pipe between two ponds – not in groundwater samples or well samples. Dr. Gillham was of the view that Well 7 would not have contributed. He found that there was weak (if any) evidence that Well 7 was vulnerable, and that there was no evidence that it contributed to the outbreak.

Dr. Gillham further noted the difference between the hydrogeological settings of Wells 5, 6, and 7. The bedrock fracturing at Well 5 is much greater than it is at the other two locations. There is a highly weathered zone, with a close spacing of horizontal and vertical fractures, which provides a good vertical connection with the upper 3–4 m of weathered bedrock. Much less water would move through the vertical fracturing near Wells 6 and 7. He also noted that the major water-producing zones for Well 6, and especially for Well 7, were significantly deeper than those for Well 5.

Dr. Gillham noted a hydraulic connection to the surface of both Wells 6 and 7, but the degree of this connection is unclear. The chemistry of water from Well 7[26] is very different from that of water from Well 5 or 6, which suggests that each well has a different source of water. Dr. Gillham concluded that "there remains no doubt that Well 5 was the source of contamination. It cannot be stated that Well 6, and perhaps Well 7 to a degree, are totally absent of risk. Nevertheless, there is no evidence that they contributed to the April and May 2000 outbreak."

[26] Based on nitrate, sulfate, sodium, and chloride concentrations.

Dr. Gillham considered three possible pathways of the contaminated water:

- an infiltration of contaminated water at the potential source areas, followed by horizontal flow in the bedrock;
- an overland flow from the source areas, resulting in the inundation of the area around Well 5, followed by a rapid infiltration through springs and seeps; and
- an infiltration at point sources in areas where the overburden has been breached, followed by horizontal flow in the bedrock.

Dr. Gillham concluded that the first of these possible pathways – the infiltration followed by lateral transport in the bedrock – was improbable. He found that the overburden acts as a semi-confining layer; the residence time in the overburden could be up to a year, and he cited low *E. coli* in soil samples as well as generally low *E. coli* in the monitoring wells. With respect to the second possible pathway, he found this to be topographically unfavourable, given the rise of land between the Biesenthal farm and Well 5, and found the hydrologic modelling to be inconclusive. He also cited the continuing discharge of *E. coli* from the spring near Well 5. Dr. Gillham found the third posible pathway – point source infiltration caused by breaching of the protective overburden, followed by rapid transport to the bedrock – to be the most likely explanation. In preferring the third pathway, he cited the high concentrations of *E. coli* in the bedrock at monitoring Well 12 near the Biesenthal farmyard. He also cited the August pump tests in which *E. coli* increased at monitoring Well 2, monitoring Well 12, and Well 5 after pumping.

A consulting engineering firm, B.M. Ross and Associates Ltd., was retained by the Municipality of Brockton to investigate the cause of the outbreak. Golder Associates Ltd. was subcontracted to carry out a hydrogeological study. Like Dr. Gillham, the authors of the B.M. Ross report concluded that Well 5 was the most probable source of the contamination. Daniel Brown, of Golder Associates, was the senior hydrogeologist responsible for the report. He also agreed that there was an overwhelming case for Well 5 being the cause of the outbreak in May 2000. The factors leading him to this conclusion included the shallowness of the overburden; the shallowness of the aquifer itself; a known source of *E. coli* O157:H7 close to Well 5; the timing of the pumping of the various wells, taking into account the incubation periods for *E. coli* and *Campylobacter*; the laboratory results, including the heavy contamination of

Well 5 from May 23 to June 5 and the satisfactory results from Wells 6 and 7 in this period; and microbiological and epidemiological evidence.

The B.M. Ross report concluded that the mechanism for transporting contaminants to Well 5 could be either via the aquifer or by overland flow. B.M. Ross developed a hydrological model suggesting that the combination of saturated soil conditions due to rainstorms from May 8 onward, combined with the intensity and depth of precipitation on May 12, could have caused ponded water on Lot 20 of the Biesenthal farm to overcome a topographical divide so that waters from the barnyard area could have reached Well 5. The report concluded that the confluence of factors required for such ponding and flow would be a very rare occurrence and may never have happened before.

Dr. Stephen Worthington is a karst hydrogeologist and, as noted above, was called by the Concerned Walkerton Citizens. He also testified that in his opinion, Well 5 was the overwhelming source of contamination.[27] Dr. Worthington also stated that the overland flow theory was less likely than the point source infiltration theory. He discounted the potential for overland flow causing water to enter the aquifer through the reversing spring because of the volume of water flowing from this spring in May. His conclusion is consistent with Dr. Gillham's: some breach through the thin overburden in the proximity of Well 5 allowed the bacteria to enter the aquifer. The shallowness of the overburden was critical to Dr. Worthington's opinion.

A fourth expert testified about the pathway of the contamination. Dr. Michael Goss, chair of the University of Guelph's land stewardship program, was critical of the overland flow theory. He noted that:

- by May 12, rain would have promoted the infiltration of bacteria that were close to the soil surface into deeper layers;
- fall tining, root pores, tillage practices, and crop location and growth would also encourage infiltration into the soil and help to prevent surface runoff; and
- the crops showed no sign of damage from the significant ponding assumed by the B.M. Ross model.

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[27] I noted above the qualification to his opinion in his report of November 23, 2000.

All of the experts support the conclusion that Well 5 was the source of the contamination in May 2000. The preponderance of evidence indicates that the contamination most likely entered Well 5 by way of a point source breach of the overburden, and was then swiftly transported through the bedrock to the aquifer supplying the well. I agree with this conclusion. I am, however, unable to entirely rule out the overland theory.

4.9 The Timing of the Contamination

It is impossible to determine the exact time when the contamination first entered the system. I conclude, however, that the residents of Walkerton were probably first exposed on or shortly after May 12. This conclusion is supported by the epidemiological evidence, the evidence of the health care providers that treated the ill and vulnerable groups, anecdotal evidence from residents, and the timing of the heavy rainfall.

The main causes of illness and disease in the population were two bacteria: *E. coli* O157:H7 and *C. jejuni*. The incubation period for most cases of *E. coli* O157:H7 and *C. jejuni* is approximately three to four days. In Walkerton, the onset for illness of the majority of cases occurred after May 12. There was a significant clustering of illnesses between May 17 and 19 and a smaller cluster between May 22 and May 24.

Well 5 was the main source supplying the system from May 9 to May 15. Well 6 cycled on when needed, though it appears to have been out of service from the evening of May 13 onward as a result of an electrical mishap. Well 7 was not operating from May 9 until May 15 at 6:15 a.m. The conclusion that the contamination entered the system on or shortly after May 12 is consistent with a conclusion that Well 5 was the source of the contamination and inconsistent with Well 7's having been the source. It does not rule out Well 6 as a source of contamination.

4.9.1 The Onset and Clustering of Illnesses: Epidemiological Evidence

After the outbreak, the Bruce-Grey-Owen Sound Health Unit and Health Canada conducted an epidemiological study of the illnesses and deaths associated with the contamination of the Walkerton water system. They concluded that the predominant exposure dates were between May 13 and May 16.

Dr. Andrea Ellis supervised a Health Canada team assigned to conduct epidemiological and environmental investigations in order to determine the outbreak's cause and scope. The epidemiological team developed a case definition to help determine the outbreak's scope. A "case" was defined as a person who:

- had diarrhea or bloody diarrhea; or
- produced stool specimens positive for *E. coli* O157:H7 or *C. jejuni*; or
- had hemolytic uremic syndrome (HUS); and
- experienced the onset of illness between April 15 and June 30, after exposure to Walkerton water.

As discussed in Chapter 2 of this report, the health unit, using the case definition, estimated that 2,321 people became ill as a result of the outbreak. It prepared an epidemic curve based on a person's self-reporting of the date of the onset of illness (see Figure 2). The curve demonstrates that the onset of illness for the majority of cases of illness began after May 12 and continued until early June. In general, a significant clustering of cases of illness occurred between May 17 and May 19. A second, smaller cluster of cases of illness occurred between May 22 and 24.

Dr. Pierre Payment testified that the first general cluster (or peak of cases of illness), occurring from May 17 to May 19, included cases of bloody diarrhea, whereas the second general cluster of cases of illness, occurring from May 22 to May 24, did not. He concluded that the second cluster probably involved a pathogen different from that involved in the first cluster. Dr. Payment also testified, on the basis of epidemiological information, that five peaks of cases of illness occurred in the Walkerton outbreak. This observation suggests the involvement of multiple pathogens. The peaks, or clusters, of cases of illness are shown in Table 7.

The health unit's epidemic curve indicates a small number of people who reported an onset date of illness before May 14 and whose stool cultures tested positive for *E. coli* O157:H7. However, the stool cultures were not taken and confirmed until late May. Accordingly, in Dr. Ellis's view, it is not certain that these people were experiencing illness due to *E. coli* O157:H7 infection before May 14. One must therefore be careful in attaching a great deal of weight to

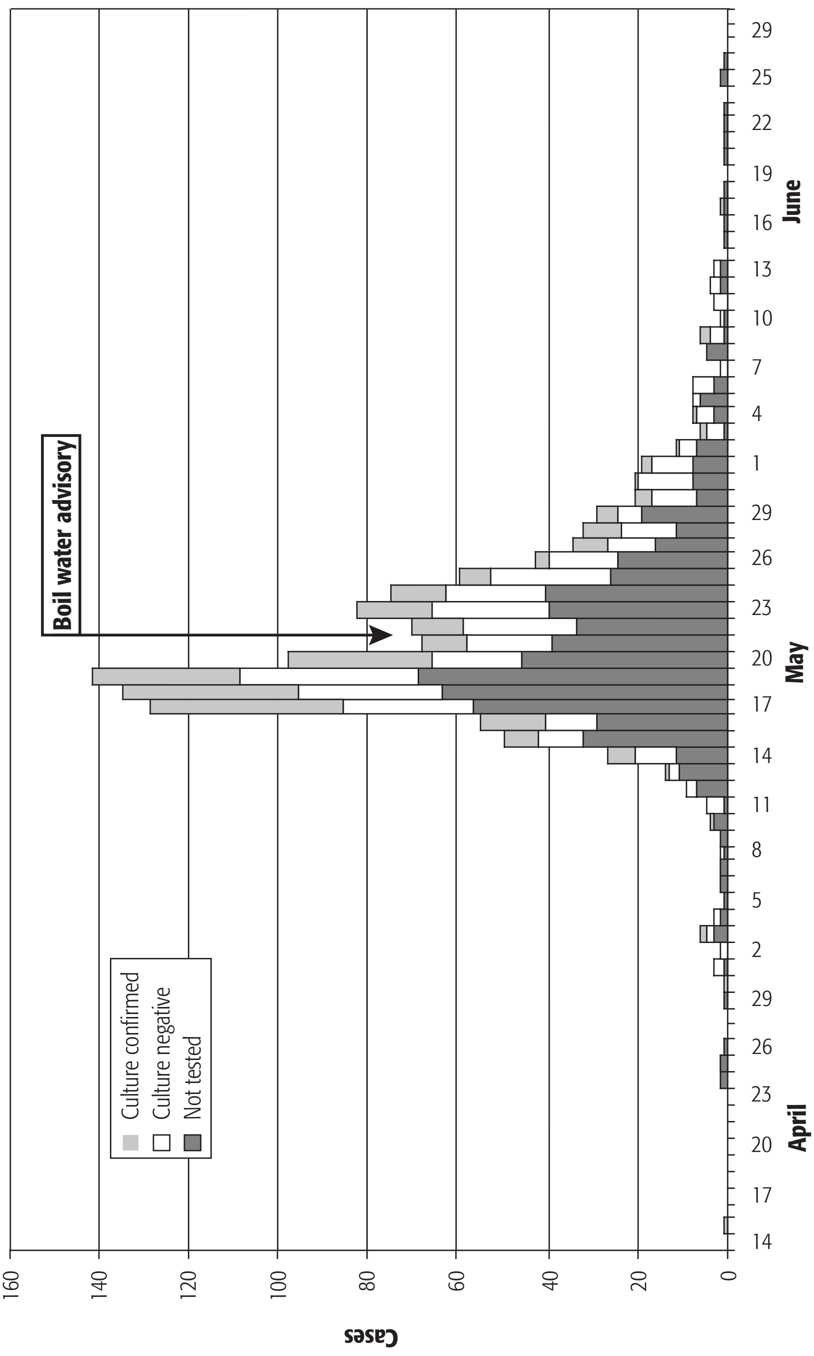

Figure 2 Epidemic Curve, Walkerton, 2000
Number of cases (n=1335) Date of onset missing for 11 reported cases

these reports. This becomes important in trying to determine the time that the contamination first entered the system.

Table 7 Clusters or Peaks of Cases of Illness, Walkerton, May 2000

Type of Pathogen or Symptom	Date of Peak
C. jejuni cases	May 19–21
Cases involving bloody diarrhea	May 17–20
E. coli cases	May 19–22
Cases involving other symptoms	May 17–20 May 21–25

4.9.2 Other Evidence Regarding Onset Dates

In addition to the health unit's report recording the self-reported information, the other major source of information about the outbreak was the institutions responsible for treating those who became ill. This evidence indicates that the onset of diarrhea began on May 16. Based on a three- to four-day incubation period, the earliest exposure appears to be between May 12 and May 14.

The Walkerton hospital emergency department's records of patient visits and telephone inquiries are an important source of information. Before the May 2000 outbreak, the number of patients who visited the emergency department of the Walkerton hospital each month was approximately 1,100. In May 2000, there were 1,829 visits – 66% above the normal rate.

In April 2000, the maximum number of emergency room registrations for any day in the month was 55. On May 16, May 17, and May 18, the number of patients who visited the emergency department of the Walkerton hospital ranged from 36 to 50, which the hospital administrator, Dianne Waram, testified was within the normal range. On May 19, there were 48 visits to the emergency room, which also was within the range of normal use. The people visiting the hospital on May 19 included eight patients who had experienced three days of diarrhea that had turned bloody, which prompted them to come to the hospital. Assuming an onset date of diarrhea symptoms of May 16 for these eight patients and allowing for a three- to four-day incubation period indicates a likely exposure date of May 12 or May 13.

On May 20, and for two weeks after that , the number of visits to the Walkerton hospital significantly exceeded the range of normal use. Table 8 shows the number of patients examined in the emergency department from May 20 to June 3.

Table 8 Walkerton Hospital Emergency Department, Patients Examined, May 20–June 3, 2000

Date	Number of Patients
May 20	67
May 21	58
May 22	84
May 23	84
May 24	113
May 25	117
May 26	106
May 27	111
May 28	87
May 29	116
May 30	64
May 31	106
June 1	95
June 2	81
June 3	62

A chart prepared by the Walkerton hospital documents the number of telephone calls to the emergency department between May 14 and May 31 that were related to the symptoms associated with *E. coli*. On May 14, May 15, and May 16, the hospital did not receive any calls pertaining to *E. coli*–type symptoms. Table 9 shows the incidence of these calls from May 17 to May 28.

An additional 90 calls related to *E. coli* were made to the emergency department by members of the public from May 29 to May 31, totalling 848 calls from May 17 to May 31. Individuals reported diarrhea and vomiting and sought information on measures they should take. Given that the first phone calls were received on May 17 and May 18, a three- to four-day incubation period indicates a likely exposure date between May 13 and May 15.

Table 9 Telephone Calls to Walkerton Hospital Emergency Department Concerning *E. coli*–type Symptoms, May 17–28, 2000

Date	Number of Calls
May 17	1
May 18	4
May 19	6
May 20	121
May 21	141
May 22	51
May 23	80
May 24	137
May 25	78
May 26	29
May 27	47
May 28	63
Total	758

Donald Moore, the administrator of the Brucelea Haven nursing home, testified that the first cases of illness occurred there on May 17. Using a three- to four-day incubation period suggests a likely exposure date from May 13 to May 14.

Catherine Reich testified that she called Mother Teresa School on May 18 to tell the secretary that her daughters were ill and would not be attending school. She was told by the secretary that 20 other children were ill and out of school. Ms. Reich's daughters had been sick since May 16. At about 8:30 p.m. that day, one of her daughters was admitted to the Owen Sound hospital under the care of Dr. Kristen Hallett. Also on May 18, in the afternoon, a young boy was admitted to the Owen Sound hospital under the care of Dr. Hallett. This boy had bloody diarrhea as of the evening of May 18.

On May 19, JoAnn Todd, administrator of the Maple Court Villa retirement home, reported an enteric outbreak among the resident population when three residents became ill with vomiting and diarrhea.

Further, on May 20, a third child (age two and a half) was admitted to the Owen Sound hospital with gastroenteritis. On May 21, this child experienced abdominal cramping, fever, vomiting, and bloody diarrhea. After developing symptoms of HUS, she was transferred to London, and on May 23 she died as a result of *E. coli* O157:H7 infection.

The health unit received the first laboratory results from the Owen Sound hospital indicating the presence of *E. coli* O157:H7 in a patient's stool sample on May 20. Later results indicated that *C. jejuni* was also present in many of the patients.

4.9.3 The Onset of Illnesses Leading to Death

The Office of the Chief Coroner and its Expert Review Panel identified seven deaths associated with the Walkerton outbreak. Information about the deaths is summarized in Table 10, in order of the onset date of illness. This evidence is consistent with the conclusion that the contamination probably entered the system on or shortly after May 12.

Table 10 Deaths Associated with the Walkerton Outbreak, 2000

Date of Onset	Date of Death	Did the Outbreak Cause Death or Contribute to Death?	Probable Outbreak Organism
May 18	May 22	Contribute	*E. coli* O157:H7
May 18	May 23	Cause	*E. coli* O157:H7
May 19	July 25	Contribute	C. jejuni
May 19	May 24	Cause	*E. coli* O157:H7
May 20	May 29	Contribute	*C. jejuni*
May 20	May 30	Cause	*E. coli* O157:H7
May 21	May 24	Cause	*E. coli* O157:H7

As mentioned, the average incubation period from infection to onset of symptoms for both *E. coli* O157:H7 and *Campylobacter* is three to four days. This is consistent with the evidence regarding the incubation period for the person who died on May 23, who was the only non-resident of Walkerton to die as a result of the outbreak. The period between her last exposure to Walkerton water and the onset of her symptoms provides a general indication of the length of the incubation period for *E. coli* O157:H7 in the Walkerton outbreak. Her last exposure to Walkerton water was on May 14, and the date of the onset of her symptoms was May 18. Therefore, her likely incubation period was four days, which is in keeping with the experts' evidence.

Since the maximum incubation period for *E. coli* O157:H7 is eight days and the shortest period is approximately one day, the outside exposure dates for the five people whose deaths were caused or contributed to by *E. coli* O157:H7 – who all began experiencing symptoms between May 18 and May 21 – are May 10 and May 20. However, given that the evidence indicates that the average incubation period for *E. coli* O157:H7 is three to four days, it is likely that these five people were exposed to the *E. coli* O157:H7 bacteria between May 14 and May 18.

Similarly, given that the maximum incubation period for *C. jejuni* established in the evidence is 10 days, the earliest possible exposure dates for the two people whose deaths were contributed to by *C. jejuni* – who began to experience symptoms on May 19 and May 20, respectively – are May 9 and May 10, respectively. Since the evidence indicates that the average incubation period for *C. jejuni* is three to four days, these two people were probably exposed to the *C. jejuni* bacteria between May 15 and May 17.

4.10 The Chlorine Dosage at Well 5 and Residuals in the System

Given my conclusion that the contamination entered the system through Well 5, why did the chlorine added at Well 5 not disinfect the water by killing the bacteria?

To reiterate, essentially the chlorine dose minus the chlorine demand equals the chlorine residual. It is the chlorine residual that assures disinfection. If the chlorine demand exceeds the chlorine dose, there will be no chlorine residual remaining to achieve disinfection. When heavily contaminated water enters a source such as Walkerton's Well 5, where the chlorine dose administered at the wellhead was regularly below 0.5 mg/L, the chlorine demand exerted by the contamination could completely eliminate the chlorine residual, permitting viable bacteria to enter the distribution system. It is important to specify a treatment requirement in terms of chlorine residual because chlorine demand can change as a result of fluctuating raw water quality. If chlorine demand rises, then the chlorine dose must be increased to ensure that the chlorine residual is maintained.

Water from Well 5 was disinfected by a sodium hypochlorite injection system. The sodium hypochlorite contained 12% chlorine. The solution was diluted with water in a mixing tank before being injected into the water that was pumped from the well to the distribution system. There is some uncertainty about how much the Walkerton PUC diluted the sodium hypochlorite before injection. PUC records reported a "dilution factor" of 10/30, which I take to mean 1 part sodium hypochlorite solution to 3 parts water (a dilution factor of 1 in 4). Based on information obtained from Stan Koebel through his counsel, the dilution factor actually used by the PUC was closer to 1 in 6 – that is, 1part sodium hypochlorite to 5 parts water, based on mixing 5 gallons of sodium hypochlorite with water to make 30 gallons of solution in the mixing tank.

Dr. Peter Huck, a professor and NSERC chairholder in water treatment at the University of Waterloo and a member of the Walkerton Commission Expert Review Panel, calculated the maximum chlorine dose possible at Well 5, based on his assessment of the capacity of the feed pump used at the well in May 2000, the flow recorded by SCADA data, and assuming no dilution of the 12% sodium hypochlorite solution. He concluded that in these circumstances, the maximum chlorine dose that could be placed in the water leaving Well 5 was 2.3 mg/L. Assuming the information provided by Stan Koebel about a 1-in-6 dilution factor, Dr. Huck calculated that the maximum chlorine dosage at Well 5 would be reduced to approximately 0.4 mg/L. This is significant, because it means that given its chlorination practices, the Walkerton PUC could not possibly have met the Chlorination Bulletin's requirement of maintaining a chlorine residual of 0.5 mg/L after 15 minutes of contact time.

Stephen Burns, of B.M. Ross and Associates Ltd., calculated the chlorine dosage at Well 5 in a different manner than did Dr. Huck. Mr. Burns calculated the average for January through April 2000 based on chlorine consumption records and recorded pumpages. Using this information, Mr. Burns calculated the average dosage at Well 5 to be 0.44 mg/L.

The evidence of both Dr. Huck and Mr. Burns is that it was highly unlikely, given the practices of the Walkerton PUC, that a chlorine dose of 0.5 mg/L was ever introduced into the water at Well 5.

There is no reliable evidence of the chlorine demand of the raw water entering any of the wells before the outbreak. It is, however, clear that in order to cause the degree of illness evident in May 2000, a significant glut of contamination entered the system and was not disinfected at the well site.

There is also no reliable information about the normal chlorine demand of the Walkerton water distribution system before May 2000. Mr. Burns noted that in early June, prior to the extensive swabbing and superchlorination program implemented by the Ontario Clean Water Agency, the difference between residuals at the pumphouses and those in the distribution system was generally greater than 0.6 mg/L. This would seem to indicate a high chlorine demand in the distribution system. That high level of demand would be a function of the chemistry of the water, the large amount of iron piping, the extensive biofilm[28] in the distribution system, and other conditions of that nature. Mr. Burns was of the view that on the basis of his calculations of average dosages, and the demand exerted by the distribution system of 0.6 mg/L, on average, there would under normal circumstances have been no chlorine residual in the distribution system.

I am reluctant to place too much weight on the 0.6 mg/L difference between chlorine residuals at the wells and in the distribution system as measured in early June 2000. Chlorine demand may in some circumstances be a function of chlorine dosage. For example, as more chlorine is applied, interactions may occur that would not otherwise have occurred, such as more biofilm dissolution or interactions with iron piping. By early June, the system had been subjected to significantly higher than previous chlorination levels, including the superchlorination initiated on May 19, as well as significant flushing. The chlorine demand in the system measured in early June may well have appeared higher as a result of higher chlorine dosage. The chlorine demand at the lower chlorine dosage typically applied by the PUC would likely have been substantial but possibly lower than the 0.6 mg/L dosage that was estimated in June 2000, when high chlorine doses were applied to the system.

However, I conclude that it is likely that the chlorine residual level in the distribution system under normal operating conditions was very low. I say this on the basis of the dilution practices at Well 5, the practice of the PUC staff to keep chlorine doses at low levels, the degree of interactions with iron piping, and the amount of biofilm in Walkerton's water distribution system. If the incoming contaminated water in May 2000 had an unsatisfied chlorine demand – as it surely did – then the residual in the system, if there was any, would likely have been be consumed quite rapidly.

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[28] Biofilm is an accumulation of bacterial growth on the inside of water distribution system pipes. The biofilm in the Walkerton water distribution system consisted primarily of *Leptothrix*, a harmless soil bacterium.

4.11 Chlorine and Turbidity Monitoring at Well 5

Continuous chlorine residual and turbidity monitors would have prevented the outbreak. It is very probable that daily chlorine residual monitoring would have significantly reduced the amount of contamination that entered the system.

During the relevant time, the MOE had two requirements for monitoring chlorine residual for groundwater sources. The first applied to the more vulnerable groundwater sources: those that were under the direct influence of surface water. Section 4.2.1.1 of the ODWO provides that groundwater that is under the direct influence of surface water and not undergoing filtration should be monitored for disinfectant residual (equivalent to free chlorine) by continuous monitoring.

It also required that groundwater sources under the direct influence of surface water should monitor turbidity levels, using a grab sample, every four hours or by continuous monitoring. For the sake of simplicity, I will refer to this requirement relating to turbidity as a requirement for a continuous turbidity monitor. It is important to combine continuous chlorine residual monitoring with effective turbidity monitoring. In some instances, turbidity can reduce the disinfection effectiveness of chlorine. In section 4.2.1.1, the ODWO states that "[v]iable coliform bacteria have been detected in waters with turbidities higher than 3.8 NTU even in the presence of free chlorine residuals of up to 0.5 mg/L and after a contact time in excess of thirty minutes."

Increases in turbidity may indicate excessive contamination, even when chlorine residual monitoring may not disclose the problem. Turbidity rises can interfere with disinfection because they are often accompanied by substances that result in increased chlorine demand. Turbidity may also result from aggregated bacteria and particulates in which bacteria can be embedded and thereby protected from disinfection.

For the reasons set out previously, I have found that Well 5 was a groundwater source under the direct influence of surface water; it therefore should have had continuous chlorine residual and turbidity monitors.

There is a strong probability that when the contamination entered Well 5 in May 2000, the increased chlorine demand overwhelmed the chlorine dose being applied at the well; resulting in inadequate disinfection of the water.

The Chlorination Bulletin sets out chlorine residual monitoring requirements of treated water before it enters the distribution system. Section 3.1.2 of the Chlorination Bulletin provides:

> The chlorine residual test must be performed as frequently as needed to ensure that an adequate chlorine residual is maintained at all times. Such considerations as raw water quality and the resultant variation in chlorine demand, and changing flow rates must be taken into account.

Under this requirement, chlorine residuals are taken manually by waterworks operators. This is the method ostensibly employed by the Walkerton PUC. For years, dating as far back as 1979, the operators of the Walkerton PUC purported to monitor chlorine residuals on a daily basis. Daily entries of chlorine residuals were made in the daily operating sheets. At the time Well 5 was approved in 1979, it was agreed between the Walkerton PUC and the MOE that chlorine residuals would be monitored daily. Through its inspection program, the MOE was aware that the PUC purported to take residuals daily, and it accepted this procedure.

Until the spring of 1998, the Walkerton PUC operators used a colorimetric chlorine residual analyzer that was able to measure chlorine residuals up to a level of 0.5 mg/L in units of one tenth (e.g., 0.1, 0.2, 0.3, 0.4, 0.5, and so on). After 0.5 mg/L, the next possible measurement was 0.75 mg/L. In early 1998, they began using a more sophisticated HACH digital chlorine residual analyzer, which measured residuals in units of 0.01 mg/L.

The evidence at the Inquiry disclosed that for many years, the Walkerton PUC operators did not regularly take chlorine residuals on a daily basis. Rather, the PUC employees who attended the well house would usually write a number, nearly always either 0.5 or 0.75, in the appropriate column of the daily operating sheet, falsely indicating that a residual had been taken and an acceptable reading obtained. On some occasions – it is not clear how often – chlorine residuals were in fact taken. It was never the practice of the Walkerton PUC operators to take turbidity readings during their daily attendances at the well sites.

I will set out my conclusions about the conduct of these operators in greater detail in Chapter 5 of this report, when I discuss their roles in these events. It is sufficient for the purposes of discussing the physical cause of the events of

May 2000 to note that their practice was, on most occasions, not to take chlorine residuals and to make misleading entries in the daily operating sheets.

This practice continued in May 2000. The daily operating sheet for Well 5 shows chlorine residuals for each of the nine days that Well 5 operated during the period from May 1 to May 15 as being 0.75. Given that the quality of raw water varies and that the instrument used in May to measure chlorine residuals measurer in use in May was calibrated to measure differences as small as 0.01 mg/L, there is no possibility that these were accurate numbers. No one suggested that they were. Of particular relevance to the issue of the physical cause are the entries for May 10 to May 15 inclusive. Each entry, as I have said, was 0.75. If the contamination entered the system during this period, as I have found that it did, and if chlorine residual readings had been taken, they would have disclosed either no chlorine residual or a residual significantly less than 0.75. I have no doubt that during this critical period, no chlorine residual readings were in fact taken at Well 5. That is most unfortunate, because if daily chlorine residual readings had been taken during this period there is a strong likelihood that the chlorine demand of the incoming contamination was such that no residual would have been present and that the appropriate measures – either increasing the chlorine dosage or shutting off the well – could have been taken.

One possible exception to the point that taking chlorine residual readings would have disclosed the incoming contamination arises from the fact the readings might have been taken precisely when there was no contamination in the incoming well water. That seems most unlikely, given the enormous amount of contamination that was disclosed by test results from samples taken on May 15 and the fact that the raw water at the well days later continued to be massively contaminated.

Another possible exception to the effectiveness of daily chlorine residual monitoring as an alarm mechanism would be the presence of high turbidity, which in some circumstances could possibly preclude a drop in the chlorine residual. However, given the massive amount of contamination that entered the system, it is most unlikely that high turbidity operated in this manner at the time the Walkerton water system became contaminated in May 2000.

Until the outbreak, there was a dearth of data concerning turbidity at Well 5.[29] In the aftermath of the outbreak, turbidity was closely monitored and some very high turbidity levels were detected in samples taken from fire hydrants. I am satisfied, however, that these readings do not support a finding that there was a major influx of turbidity in conjunction with the contamination.

On May 24, the Central Ontario Analytical Laboratory tested turbidity at 33 locations. Of the 33 samples, 19 exceeded the maximum acceptable concentration for turbidity. I am reluctant to place any weight on the May 24 results as indicating that excessive turbidity entered the water system after May 12. What appear to be very high distribution system results were, in fact, taken from hydrants that were not flushed immediately before they were sampled. Therefore, a sample containing 85 NTU was taken from a hydrant near Walkerton Daycare, but it is not known when the hydrant was last flushed. The same is true of an 18 NTU reading derived from a sample purportedly taken at "Sacred Heart High School." These high readings do not reflect water quality throughout the distribution system. Similarly, they do not assist me in determining whether turbidity entered the system on May 12 or afterward and do not indicate turbidity levels at Well 5 at the time of contamination.

Importantly, there is no evidence of cloudy water or excess turbidity being observed by residents of Walkerton at any time after May 12. Cloudiness in water starts to become visible above 5 NTU, and the ODWO established an aesthetic objective of 5 NTU for turbidity at the point of consumption. Had there been a turbidity problem in the distribution system during the outbreak that resulted in counts of anywhere near those found on May 24, it is most probable, given the outbreak, that residents would have recalled it.

Assuming, however, that there was turbidity, turbidity samples should have been taken daily. They were not. Section 4.2.1.3 of the ODWO provides that daily turbidity monitoring was voluntary unless routine microbiological sampling indicated no adverse water quality. Clearly, Well 5 did not come within this exception.

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[29] Turbidity in the Well 5 water was measured on ten occasions in 1979–80. On two of these occasions, the turbidity levels of 1.8 NTU and 3.5 NTU exceeded the maximum acceptable concentration, and on another it was at the maximum level of 1 NTU. Over the next 20 years, turbidity was recorded on only six occasions. In each instance, it was below the maximum acceptable concentration of 1 NTU.

The failure of the Walkerton PUC to take daily turbidity samples is another example of a government guideline that was not followed by the PUC. However, it should be noted that MOE inspectors, although aware that turbidity monitoring was not being conducted, did not object. Nevertheless, the point is that if there was turbidity, proper monitoring should have disclosed that problem.[30]

That brings me back to the failure of the PUC to take chlorine residual readings daily, as it was expected to do. Had it done so, it is very likely that the PUC would have discovered the incoming contamination within 24 hours or possibly 48 hours. The result of this monitoring – the monitoring that the PUC ostensibly did and that the MOE expected it to do – would not likely have prevented the outbreak, but it could have led to steps that would have greatly reduced the outbreak's scope of the illnesses and probably reduced the number of deaths in the community.

Before leaving this issue, there is a further matter that needs comment: the requirement for chlorine residuals is that a level of 0.5 mg/L after 15 minutes of contact time be maintained. The 15 minutes of contact time give the contamination an opportunity to exert its full demand on the chlorine. Chlorine residual readings taken before 15 minutes of contact time may therefore be higher than would be the case after the full 15 minutes. It is not clear that when the PUC operators actually did take residuals, they waited 15 minutes before obtaining a reading. However, in the end, that does not matter – because, as I have found, PUC operators did not take residuals during the critical period.

4.12 The Operation of Well 7 Without a Chlorinator

Well 7 was operated without a chlorinator during two periods in May: from May 3 to May 9 and from May 15 to May 19. In these periods, Well 7 was Walkerton's only source of water. This raises the question of whether operating Well 7 without a chlorinator caused, or contributed to the extent of, the contamination of the water distribution system.

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[30] Because I consider it unlikely that there was turbidity in sufficient amounts to have rendered chlorine residual monitoring ineffective, I do not, in this report, analyze the failure of the MOE to require daily turbidity monitoring.

The total volume of the system, excluding the standpipes, is approximately 1,100 m^3. The average length of time that the water resides within the system is less than one day. This means that on an average day, all the water will be used up and replaced by new water within 24 hours. The total volume of the standpipes is approximately 4,900 m^3, only a portion of which is active volume. Normally the standpipes are kept reasonably full to provide both the required pressure and water for fire protection.

When Well 5 began pumping on May 9, Well 7 had been providing water without chlorination since May 3. Given the average residence time of water in the system and the practice of maintaining low chlorine residuals, there was essentially no chlorine residual in the distribution system when Well 5 began pumping on May 9. Dr. Huck was of the opinion that if most of the *E. coli* entering Well 5 did so on the May 12 weekend, it is unlikely that Well 7's operation without chlorination from May 3 to May 9 had a significant impact. The reason for this opinion is that between May 9 and May 12, the unchlorinated Well 7 water would have been largely displaced. Since the distribution system is not homogeneous, there may have been specific areas where the earlier presence of unchlorinated Well 7 water might have made a difference, but Dr. Huck stated that with existing information it was impossible to quantify any such effect. I accept Dr. Huck's opinion, and agree that the operation of Well 7 without a chlorinator from May 3 to May 9 did not cause or contribute to the extent of the contamination in May 2000.

Well 7 was also operated without a chlorinator from May 15 to 19. Well 5 was turned off on May 15 at 1:15 p.m. and was not turned on again until May 20. Starting on the late afternoon of May 19, Stan Koebel superchlorinated the system. The contamination had entered the system by the time Well 7 was turned on without a chlorinator on May 15 at 6:15 a.m. The operation of Well 7 without a chlorinator did not add to the contamination. The contaminated water from Well 5 would have remained in the system for at least 24 hours after Well 5 was turned off on May 15 at 1:15 p.m. It remained in dead ends for much longer.

The effect of operating Well 7 without a chlorinator in this later period was to exclude any disinfecting assistance that might have been provided by that well's water mixing with the contaminated water in the distribution system. Both the ODWO and the Chlorination Bulletin merely require the level of chlorine residual in the distribution system to be "detectable." In this system, even if the chlorination in Well 7 had been maintained at the proper level, it is unlikely that achieving only a "detectable" disinfectant residual in the distribution system would have been an amount great enough to significantly eliminate bacteria that had entered through another source.

The general purpose of a distribution system disinfectant residual is to depress biofilm growth and potentially to address point source disturbances in the distribution system; it is not intended to eliminate massive contamination that was not eradicated at source. It is impossible to measure the extent to which operating Well 7 without a chlorinator from May 15 to May 19 may have contributed to the extent of the distribution system's contamination, but it is fair to say that it would likely not have been great.

4.13 Wells 6 and 7

Much of the information regarding Wells 6 and 7 has been dealt with above in the discussion of my reasons for finding that the evidence supports contamination entering through Well 5. The microbiological water samples indicated gross contamination at Well 5 immediately after the outbreak and no contamination at Wells 6 and 7. There is a clear epidemiological link between the farm beside Well 5 and the predominant human outbreak strains of both *E. coli* O157:H7 and *Campylobacter*. The pumping schedule of the wells indicates that Well 5 provided most of the water in the crucial period of May 10 to May 15. Having discussed that evidence thoroughly above, in this section I focus on the hydrogeological setting of Wells 6 and 7 and their physical construction. I find it most unlikely that either Well 6 or Well 7 caused or contributed to the outbreak of May 2000.

Well 6 is located approximately 3 km west of Walkerton in the former Brant Township, adjacent to Bruce County Road 2. It is slightly more than 3 km northwest of Well 5. Well 6 was constructed in 1982 to a depth of 72.2 m. Depth to bedrock was 6.1 m, with a casing to 12.5 m. Well 6 is equipped to be capable of pumping approximately 16.9 L/second to 21.3 L/second, or 1,460 m^3/day to 1,832 m^3/day. This represents approximately 42–52% of the water requirements of the system.

Flow profiling carried out by Golder Associates Ltd. found that 50% of the flow was found at a depth of 19.2 m; 5% from 27.7 m to 29.3 m; 25% from 34.4 m to 35.3 m; 15% from 47.2 m, 50.4 m, and 54.0 m; and 5% from 61.6 m or greater. The Golder investigation concluded that much of the water comes from intermediate producing zones that are hydraulically connected to shallow water in the nearby wetland and to a nearby private pond. Dr. Robert Gillham was of the view that there was probably less than 1 m of overburden between the bottom of the pond and the top of the bedrock, and very little protection for the aquifer.

Dr. Gillham also noted a connection between Well 6 and springs in the area. However, given that the first water-bearing zone is approximately 17 m below the surface, this connection between surface water and Well 6 is not as direct or extensive as that at Well 5.

Four holes in the upper section of Well 6's casing were observed during Golder Associates Ltd.'s investigation. It is not known whether these holes played any part in the occasional adverse bacteriological sample results that have been observed in the raw water from Well 6, but it is unlikely that they contributed to the contamination in May 2000. Two test wells (TW1-82 and TW2-82) are located near Well 6. Their potential to contaminate Well 6 was also assessed; the results were inconclusive.

Well 7 is located approximately 357 m northwest of Well 6. It was constructed in 1987 to a total depth of 76.2 m. Depth to bedrock was 6.1 m, the well with casing extending to 13.7 m. Well 7 is capable of pumping approximately 50.8 L/second to 56.8 L/second or 4,390 m^3/day to 4,908 m^3/day. This is about 125–140% of the average daily water use. Disinfection is provided by a gas chlorination system similar to that at Well 6. Since Well 7 is capable of supplying the entire demand for the system, it is also equipped with a standby diesel generator.

Water-producing zones based on flow profiling by Golder Associates Ltd. indicated that 50% of the flow came from below 72.4 m; 10% from between 72.4 m and 68 m; 30% from between 68 m and 51.5 m; and 10% from between 51.4 m and 45.7 m.[31] Well 7's water-producing zones are significantly deeper than those at Well 5. At Well 5, 100% of the water came from a depth of 5.5 m to 7.4 m. Well 6 drew 50% of its water at 19.2 m, a level deeper than Well 5. At Well 7, at least 88% of the water came from a depth of 45.7 m.

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[31] Dr. Worthington offered a different interpretation of this data. According to this interpretation, 29% of the flow comes from below 67 m in the well, compared with the 60% attributed to this zone by Golder Associates Ltd.

Both Wells 6 and 7 are artesian. However, because the top of the wellhead for Well 6 is elevated above the static water level in the well, that well does not discharge when it is not being operated. Well 7 discharges to surface when not being pumped. In May 2000, a 100-mm-diameter overflow pipe at Well 7 discharged water to the adjacent wetland when the well was not in use. This overflow pipe was equipped with a flap gate to prevent surface water from entering the well if the overflow pipe were submerged. If the pump was not on, water would flow from the pipe and there would be no problem. Some concern existed that if the pump was operating, surface water could enter through the flap gate into the well.

One small area of significant casing corrosion was found in Well 7 at a depth of 11.7 m. A test well (TW1-86) is located 2.1 m north of the Well 7 pumphouse. There is no indication of a seal around the casing at surface. It was determined that there is a poor cement bond throughout the 14.2 m of casing associated with this test well. These features could allow surface water or shallow groundwater to infiltrate this test well and ultimately affect Well 7. Golder Associates Ltd. noted a hydraulic connection between TW1-86 and Well 7 between depths of 44.8 m and 67.8 m.

There is a possible hydraulic connection between Wells 6 and 7. When Well 6 was pumped, the water levels decreased in both Well 7 and the pond adjacent to Well 6. However, because of the depth of the water-producing zones in Well 7 (45 m to 75 m), and in the light of certain water chemistry results, it is unlikely that Well 7 was under the direct influence of surface water, and hence it is unlikely that it was the source of the contamination.

Differences in water chemistry (high sulfate/low chloride in Well 7, high chloride/low sulfate in Well 6) suggest different sources of water for Wells 6 and 7. Furthermore, the relatively high nitrate concentration in Well 6 (2.52 mg/L to 9.34 mg/L) and the low nitrate concentration in Well 7 suggest a surface connection for Well 6 but no surface connection for Well 7.

4.13.1 Soil Samples

In August 2000, Golder Associates Ltd. drilled 15 bore holes at nine locations in the vicinity of Wells 6 and 7. Sixteen soil samples from six of the bore holes were analyzed for total coliforms and *E. coli*. The results indicated the presence of total coliform bacteria above the detection limit in at least one sample from each bore hole and the presence of *E. coli* in only one sample from one bore hole. Most of the counts were very low – less than 10 cfu/100 g to 40 cfu/100 g. The highest number of total coliforms was found in a near-surface sample that had a count of 1,600 cfu/100 g. The only *E. coli* count was from a bore hole sample at the detection limit of 10 cfu/100 g. The occurrence of bacteria in the bore hole samples for the areas of Wells 6 and 7 was notably lower than in bore hole samples from the area of Well 5, discussed above.

4.13.2 Pump Test Results

Golder Associates Ltd. also conducted pump tests of Wells 6 and 7 in late August and early September 2000. Those pump tests included the monitoring of water levels in nearby surface waters, private wells, and special monitoring wells. When Well 6 was pumped, water levels decreased in both Well 7 and the pond closest to Well 6.

Well 6 is susceptible to direct inputs of shallow groundwater because it has a shallower producing zone at 19.2 m. Groundwater quality tests for Well 6 indicated variable water quality; nitrate levels, turbidity, and iron concentrations fluctuated widely among zones. Well 6 exceeded the ODWO for hardness, iron, turbidity, and aluminum levels. Nitrate ranged from 2.52 mg/L to 9.34 mg/L in the individual sample zones. The majority of bacteriological results were negative from each zone. Although individual samples from two zones yielded initial positive bacteriological accounts, replicate samples from each zone yielded no organisms.

Water samples from Well 7 were of good chemical quality, and only one sample had any bacteria (2 cfu/100 mL).

Following the pump test, the results of bacteriological analyses for Well 6 groundwater samples showed low levels (1 cfu/100 mL to 26 cfu/100 mL) of total coliform organisms in 12 of the 20 samples collected during the 48-hour test, and no detectable *E. coli* bacteria. In addition, 11 of the 16 samples showed low but detectable levels of aerobic sporeformers, an indicator of surface water influence. Two of the 11 samples from Well 7 showed detectable aerobic sporeformers, and no detectable total coliform or *E. coli* bacteria were found.

4.13.3 Other Hydrogeological Evidence

Dr. Worthington also considered Wells 6 and 7. There are two springs relatively close to Wells 6 and 7. At what Dr. Worthington designated "Spring B" and described as "very close to Well 7," the flow in February 2001 was about 13 L/second, increasing to 25 L/second in April and May. By the beginning of July, Spring B was backflowing into the aquifer and potentially contaminating it. By late July, Spring B had dried up. Dr. Worthington was of the view that when Well 7 was pumped, electrical conductivity changes at Spring B occurred in response, with a lag time of one to three hours. He also noted that during a 72-hour pumping test at a test well near Well 7, the discharge of Spring B dropped by 5.2 L/second. In his view, these factors show a probability that when the spring discharge is low, surface water can be drawn into the aquifer and can travel directly through karst conduits into the pumping wells.

In July 2001, Dr. Worthington found that when Well 7 had been pumping continuously, Spring B ceased flowing, reversed its flow, and then began flowing into the aquifer. On that day, Well 7 tested positive for total coliforms.

When asked directly whether the discharge from springs A and B would have backed-up and been a source of possible contamination, Dr. Worthington replied: "I think that it would be impossible that there was backflow into the aquifer." In his view, contamination by surface water at springs A and B would generally occur at times of low spring discharge (i.e., low water flow). I find nothing in Dr. Worthington's November 23 report to change this assessment.

4.14 Other Possible Sources of Contamination

The Inquiry also heard evidence about seven other possible contamination entry points to the Walkerton water system (see Table 11). I examine each of these possible contamination entry points below. In my view, it is most unlikely that the contamination was caused by any of these possible entry points.

Table 11 Additional Potential Sources of Contamination of the Walkerton Water System

Location Type	Specific Locations	Possible Entry Mechanism
New construction	• Highway 9 (Kincardine Highway) • Old Durham Road • Ellen Avenue	• Contamination could enter when a new main is opened to an existing main if the new main is contaminated.
Fire events	• Orange Street near Willow Street	• System depressurization during fire could allow contamination to enter.
Breaks and repairs	• Four locations in March 2000	• The system is locally depressurized to carry out repairs; this could allow contamination to enter.
Storage structures (standpipes)	• Standpipe No. 1 • Standpipe No. 2	• Contamination could enter through overflow or a vent.
Cross-connections	• Private wells (8 locations) • Cisterns (many locations) • Sanitary sewage facilities	• If the well or cistern is a source and if it is pressurized to a level greater than system pressures, contamination could be discharged to the system. • If there is a connection between the sewage collection and water distribution systems, contamination could enter.
Flooding of the distribution system	• Flooding occurred May 12, 2000	• If the distribution system was depressurized and open at a flooded location, contamination could enter.
Biosolids and septage	• Fields adjacent to Wells 5, 6, and 7	• Entry could occur through a well. • The aquifer could be contaminated by surface spreading.

4.14.1 New Construction

Extensions of the water distribution system were occurring at two separate locations in the middle of May 2000: Highway 9 (the Kincardine Highway) from Circle Drive west to Wallace Street, and Old Durham Road east of Elm Street. A third location, Ellen Avenue, in the southern part of the municipality, had a new watermain constructed in March 2000. The new main remained connected but was isolated from the existing mains by means of a closed gate valve until May 16.

For the existing water distribution system to become contaminated as a result of new construction, it would be necessary for contamination to enter the new watermains and then pass into the existing main when the two are opened to one another. It would also require the new main to have a higher pressure, which could occur either by pressurizing the new main (such as would occur during testing) or, alternatively, by depressurizing the existing main while there is some pressure in the new main.

4.14.1.1 *Highway 9 (Kincardine Highway)*

Construction on the Highway 9 watermain project began on April 6, 2000. The project involved the replacement of 615 m of watermain in the southwestern part of Walkerton, along Highway 9, between Wallace Street and Circle Drive. It was at the system's southwestern extremity, on a dead end. The consulting engineer on the project was B.M. Ross and Associates Ltd., and the contractor was Lavis Construction Ltd.

On April 17, Lavis Construction began to install the new watermain. The installation was completed on May 11. Swabbing was carried out to remove debris from the watermain. The valve near the intersection of Circle Drive and Highway 9, referred to as "15+999," was opened on May 11 to enable water from the distribution system to fill the main for swabbing. The valve was again opened on May 12 because water from the distribution system was required to move a chlorine solution through the new watermain. The chlorine solution remained in the watermain during the weekend of May 13–14.

The chlorine solution was flushed from the new watermain on May 15. The valve at Circle Drive was again opened to allow water from the distribution system to enter the new main. Flushing continued until the chlorine residual had decreased to 0.8 mg/L. Three samples were taken: two from the hydrant near the Ministry of Transportation shed at the intersection of Highway 9 and Wallace Street, and one from the hydrant at the Energizer Canada plant, east of that intersection.

All three hydrant samples tested positive for total coliforms and *E. coli*. Dennis Elliott of B.M. Ross testified that although total coliforms were commonly detected in the first sampling after the standard construction industry disinfection process, this was the first occasion in his experience when *E. coli* had been detected in samples from a new watermain that had undergone that process.

Further disinfection flushing and sampling were undertaken. The new watermain was rechlorinated on May 17, and water was drawn from the distribution system through a hydrant. The chlorine solution remained in the new watermain from the afternoon of May 17 to the morning of May 18. Flushing began on the morning of May 18. Again a valve was opened, allowing water from the distribution system to enter the new main. When the chlorine residual had decreased to less than 1.0 mg/L, a second sampling was taken at the same three sites. All these samples also tested positive for both *E. coli* and total coliforms.

On May 18, Mr. Elliott had a discussion with Frank Koebel regarding the connection of the new main to the old Canadian Tire building (now known as the Saugeen Fuel and Filter building). It was explained that the owners of Saugeen Fuel and Filter were anxious for the construction area to be cleaned up before the firm's grand opening. The connection was also necessary to address fire protection concerns. As a result, on May 19, before the results from the second sampling had been received from MDS Laboratory Services Inc., the new watermain was connected to Saugeen Fuel and Filter. The owners of the building were told not to drink the water and were asked to leave a tap running to prevent backflow from the new watermain.

Until May 19, the new main at the Highway 9 project was connected to the existing system only when it was necessary to fill the new main with water. The direction of the flow on these occasions was away from the existing system. However, on May 19, the new valve connecting the watermain to Saugeen Fuel and Filter remained open.

Steve Burns of B.M. Ross concluded that the Highway 9 watermain construction did not cause or contribute to the contamination. His reasons included the following:

- The watermain was situated on a dead end. There was little risk of water moving from the dead end to the distribution system.

- The circumstances of the connection made it unlikely that there was backflow.

- The connection of Saugeen Fuel and Filter to the distribution system occurred on May 19, after the water in the system had become contaminated.

- The likely source of contamination in the samples collected from the Highway 9 project on May 18 was from Well 5.

Another consulting engineering firm, Dillon Consulting Ltd., also investigated the potential for this new watermain to have contributed to the contamination of the Walkerton water system. Dillon Consulting reported as follows:

> Although we identified some potential areas where local contamination could occur, there appears to be very little possibility that these events could have contributed to the general contamination of the water system. The location of the connection on a dead end main, and the only conduit between the new and existing mains being through a closed valve, further suggests that any contamination would have difficulty migrating to the remainder of the distribution system.
>
> On the basis of our review, there appears to be a very low likelihood that the activities surrounding the construction of the main contributed to the general contamination of the water system.

For the reasons given by Mr. Burns and Dillon Consulting, I am of the view that the Highway 9 construction did not cause or contribute to the contamination.

4.14.1.2 *Old Durham Road*

This new watermain is located on Old Durham Road, in the northeast part of the community. The main, an extension of an existing dead end main on Old Durham Road, was constructed to provide service to a new municipal industrial park. Its connection to the existing distribution system occurred on May 19, 2000. The project consultant noted that the connection was made in relatively dry conditions and that no specific problems were identified. The new watermain is located approximately 600 m from Standpipe No. 2. There were no reports or indications of any depressurizations of the system occurring at or about the time of the connection.

I conclude that the Old Durham Road construction did not contribute to the contamination of the Walkerton water system. This conclusion is based on the following reasons:

- No connection of the new watermain to the existing watermain occurred until May 19, 2000, which is after the onset-of-illness date.
- The watermain was a dead end connected to a dead end with a closed valve between the existing and new watermains. It is not possible for water to transfer from a (new) non-pressurized system to an (existing)

pressurized system. If the valve leaked, water would flow from the existing watermain to the new watermain.

- No depressurization of the existing system is reported to have occurred; depressurization would be a prerequisite for contamination to enter the existing system.

- The watermain is in the outer part of the water distribution system; this location reduces the probability that any contamination would spread quickly through the system, as did occur.

4.14.1.3 *Ellen Avenue*

Approximately 150 m of watermain was constructed on Ellen Avenue between February 14 and March 2, 2000. The watermain was flushed, pressure tested, and chlorinated in March. On March 7, a bacteriological sample was taken and submitted to the Ministry of Health laboratories for analysis. The results were reported on March 8 as 0 total coliforms and 0 *E. coli.*

On May 16, construction personnel working at a house on Ellen Avenue attempted to use water from a building service connection, but no water was available. This indicated that the new watermain was still isolated from the distribution system as a result of closed valves. The PUC was contacted, and it opened the valves on the same day.

Garry Palmateer of G.A.P. EnviroMicrobial Services Inc. provided an opinion concerning whether or not stagnant water that had tested satisfactorily in early March could have caused the observed *E. coli* contamination. He concluded that in his opinion, "it was essentially impossible for the contamination of the water main to have occurred to the extent to cause the outbreak of *E. coli* O157:H7 in Walkerton, Ontario."

4.14.2 Fire Events

During urban fire events, firefighters typically connect pumping equipment to fire hydrants. There is the possibility that the pumping equipment could reduce local system pressures to the point where contamination could be pulled into the water distribution system, through leaking pipes or cross-connections. For the contamination observed in Walkerton to have been the result of a fire event, at least one of the following occurrences would have been necessary:

- a fire event in April or early May 2000, near a connection to the water system;
- local depressurization of the distribution system;
- a source of *E. coli* O157:H7 contamination near the fire;
- a means of entry to the system (i.e., a cross-connection); and/or
- hydraulic conditions in the water system capable of causing the contamination to be distributed throughout the system.

The only fire event between April 5 and May 30, 2000, in which a connection to the water distribution system occurred was on May 1. The fire occurred at 11 Orange Street, in the northeastern part of the system. Connections were made to the distribution system at two locations near the fire. At no time was the water distribution system depressurized. The recollection of on-site firefighters as set out in the B.M. Ross report was that system pressures were approximately 550 kPa (80 psi). The fire occurred at a level lower than that of most of the water system. The system supply points (including Standpipe No. 2) are between Orange Street and the balance of the distribution system. Further, no apparent source of *E. coli* O157:H7 was identified in the area of Orange and Elm Streets. I am satisfied that the fire events did not cause the system contamination in May 2000.

4.14.3 Breaks and Repairs

Watermain breaks and repairs are another possible means of contamination. Repairs usually involve isolating the break location by closing adjacent system valves, excavating down to the watermain, installing a clamp over the break, and then opening the valves to repressurize the watermain. Break locations are typically wet, and disinfection is not normally practical. Theoretically, contamination could occur at the point of the repair and then be distributed throughout the system when the main is repressurized. For the contamination in Walkerton to have resulted from a watermain break and repair, the following conditions would have been necessary:

- a source of *E. coli* O157:H7 contamination near the break location; and
- water system hydraulic conditions capable of causing the contamination to be distributed throughout the system.

The Walkerton PUC "Water Leaks Record Book" lists four leaks for the period January 1 to June 1, 2000; they all occurred in March (see Table 12). The break locations are dispersed throughout the water distribution system. Each location was observed in June 2000; all are urban locations within easy reach of travelled roads or parking areas. None is located in obvious drainage pathways for agricultural runoff.

Garry Palmateer of G.A.P. EnviroMicrobial Services Inc. provided an opinion regarding the probability of a watermain break or repair in March 2000 causing the observed contamination. He noted two hypothetical possibilities:

- a simultaneous sanitary sewer break, at the watermain break location, that would cause raw sewage to enter the watermain; or
- cow manure being flushed into the main during the repair.

No sanitary sewer breaks occurred on the dates of the watermain breaks in Walkerton. Further, there are no obvious sources of cow manure near any of the break locations. Although the locations could be affected by surface runoff, they are all in road or parking areas and it is unlikely that the runoff contained manure. Finally, bacteriological analysis results for samples taken from the distribution system in March and April 2000 were reviewed. Although total coliforms were identified in April, none of the samples showed *E. coli* contamination. I conclude that breaks in or repairs of the water distribution system did not cause the contamination in the system.

Table 12 Watermain Break and Repair Locations, Walkerton, March 2000

Date of Break/Repair	Location	Type
March 22	130 Wallace Street	Watermain break
March 23	McGivern Street at Ridout Street	Watermain break
March 27	Colborne Street at Lutheran Church	Watermain break
March 28	6 Amelia Street	Watermain break

4.14.4 Storage Structures (Standpipes)

The Walkerton water system has two standpipes for storage. They are located in the southwestern (No. 1) and northeastern (No. 2) part of the distribution system. It is possible for storage facilities to become contaminated through openings such as overflows and vents. Birds and animals have occasionally been known to enter at these locations. During the initial stages of the water distribution system investigation by B.M. Ross & Associates Ltd., both standpipes were completely drained and examined. They were then gradually filled and placed back in service. Each standpipe was filled until water passed through the overflow. In late May 2000, staff of Collingwood Utilities Services inspected Standpipe No. 2. They reported that no sources of contamination were observed. Staff of the Ontario Clean Water Agency (OCWA) reported similar results with respect to Standpipe No. 1. Further, the mode of operation of the standpipes is to fill and empty from a single pipe on the basis of system pressures and demands. If a standpipe became contaminated, it would be highly unlikely that contamination would spread quickly throughout the distribution system, as it is reported to have done. The contamination would tend to stay in, or near, the storage structure.

No source of contamination was observed in either standpipe. In addition, *E. coli* O157:H7 is typically associated with cattle or sewage. The standpipe overflows and vents are on the top of the structure and are therefore not susceptible to agricultural contamination. I conclude that there is no probability that the water storage structures were the source of the contamination.

4.14.5 Cross-Connections

A cross-connection is a physical connection, direct or indirect, that provides an opportunity for non-potable water to enter a conduit, pipe, or receptacle containing potable water. In the Walkerton water system in May 2000, there were cross-connections to the distribution system from several private wells and several hundred cisterns, each of which was a possible source of contamination. Cisterns are storage tanks, typically located in the basements of homes, designed to store rainwater from a roof's runoff systems. Cistern water is generally "softer" in terms of calcium carbonate hardness and is frequently used for laundry systems.

Activities undertaken by OCWA during the disinfection of the water distribution system established that there were approximately 30 private water systems (wells) and approximately 470 cisterns, many of which were cross-connected to the municipal distribution system.

Private non-potable systems, including cisterns and wells, can be a source of contamination if they discharge contaminated water into the distribution system. For this to occur, they must be contaminated, they must operate at pressures greater than those in the distribution system, and there must be no functioning backflow prevention device (i.e., check valve, closed gate valve, or backflow preventer) between the private system and the communal distribution system.

Professional staff from B.M. Ross visited eight private wells on May 24, 2000, to establish whether or not the connected well was a likely source of contamination. Water samples were also taken. With the exception of the one well at RR 4, Walkerton, which had a sample result of 33 units for total coliforms and 0 for *E. coli*, all other locations had negative results for both parameters.

During the disinfection of the distribution system, contractors working under the direction of OCWA identified additional cross-connected wells. All these wells were located on residential properties in the developed urban areas. With the exception of the water system at the Energizer Canada plant, all of the systems are small. Even if they were contaminated, it would be extremely unlikely for the contamination to be distributed throughout the water system from a single small source. Inspections at the Energizer Canada plant confirmed that check valves or closed gate valves were in place.

In conclusion, although the multiple cross-connections to private systems and cisterns represented a potentially serious problem (that has since been addressed), I find it unlikely that any of these systems was the cause of the outbreak in Walkerton.

4.14.6 The Flooding of the Distribution System

On the evening of May 12, 2000, heavy rains fell in Walkerton and the surrounding area. Surface flooding occurred in several locations in Walkerton. For surface flooding to interact with the water supply and cause contamination, it would be necessary for the surface water to be contaminated and for one of the following additional situations to occur:

- inflow to a wellhead or similar water supply source; or
- inflow to a reservoir opening (i.e., a vent); or
- inflow to a watermain that is depressurized and open to the atmosphere.

The water wells and storage structures were visually examined for openings during the last week of May 2000, and it was determined they were not subject to flooding.

With respect to the water distribution system, it has been established that no depressurizations of the system occurred on May 12 or May 13. The Walkerton PUC did not report any. There were no fire events and no breaks in the system. Further, a review of the SCADA pumpage records confirms that one or more well pumps were operating continuously at normal discharge rates, which indicates that there was normal system pressurization.

Although significant surface flooding did occur on the evening of May 12 and morning of May 13, there was no apparent interaction between the flooding and either the storage structures or the water distribution system.

4.14.7 Biosolids and Septage

The Inquiry also heard evidence as to whether the land application of biosolids or septage in the Walkerton area could have caused or contributed to the contamination. Biosolids and septage are regulated under the *Environmental Protection Act,*[32] the Waste Management Regulation,[33] and the 1996 Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land. Under the Waste Management Regulation, biosolids, or "processed organic waste," means waste that is predominantly organic in composition and that has been treated by aerobic or anaerobic digestion or other means of stabilization. It includes sewage residue from sewage works that are subject to the provisions of the *Ontario Water Resources Act*.[34] Hauled sewage, also known as

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[32] *Environmental Protection Act*, R.S.O. 1990, c. E-19.
[33] Waste Management Regulation, R.R.O. 1990, Reg. 347.
[34] *Ontario Water Resources Act*, R.S.O. 1990, c. O-40.

septage, includes waste removed from a cesspool, a septage tank system, a privy vault or privy pit, a chemical toilet, a portable toilet, or a sewage holding tank.

Biosolids may be applied to land only in places where an MOE district office has approved such an application by way of an Organic Soil Conditioning Site Certificate of Approval. Septage also requires a Certificate of Approval for a hauled sewage disposal site. These sites are subject to inspection by the MOE.

In the fall of 1999, biosolids were spread on three sites in the vicinity of Walkerton. The last dates of spreading on those three sites were September 16, September 20, and October 19, 1999. Each of the sites is north and east of Wells 5, 6, and 7. Indeed, the three sites are all east of the Saugeen River watershed, so they are on the other side of the watershed divide from the wells. The closest site for a land application of biosolids to Well 5 was approximately 3 km north and east of Well 5. Although Certificates of Approval for biosolids application had been issued for sites closer to Well 5, there was no land application of biosolids on any of these sites in 1999 or 2000.

Regarding septage, there are no approved septage sites in the immediate Walkerton area. The closest sites are in Chepstow, northwest and downstream of Walkerton. Before May 2000, there were no sites upon which septage was applied near the town of Walkerton.

In the fall of 1999, it was determined that biosolids from the Walkerton sewage treatment plant were not acceptable for disposal on land because of their heavy mineral content. As a result, the last land application of these biosolids was the October 1999 application mentioned above. After October 1999, no biosolids from the Walkerton sewage treatment plant were land-applied on the sites for which Certificates of Approval had been issued.

I am satisfied that there was no septage application in the area. Further, I am satisfied that with regard to the application of biosolids, both the dates (in September and October 1999) and the location (on the other side of the Saugeen River divide, 3 km from Well 5) rule out the fall 1999 land application of biosolids as the source of the contamination in May 2000.

4.15 Summary

The conclusions I have reached in this chapter are as follows:

- The primary, if not the only, source of the contamination of the Walkerton water system was manure that had been spread on a farm near Well 5, although I cannot exclude other possible sources.

- The entry point of the contamination was through Well 5. Well 6 and, to a lesser extent, Well 7 may be vulnerable to surface contamination. However, there is no evidence to support a conclusion that the contamination entered through either Well 6 or Well 7 in May 2000.

- The residents of Walkerton were probably first exposed to the contamination on or shortly after May 12.