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Managing threats to small drinking water systems in Ontario : a risk based approach

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MANAGING THREATS TO SMALL DRINKING WATER SYSTEMS IN
ONTARIO: A RISK BASED APPROACH

by

Wendy Johnson, BAsC, Ryerson University, 2005

A thesis

Presented to Ryerson University

in partial fulfillment of the
requirements for the degree of

Master of Applied Science

in the program of

Environmental Applied Science and Management

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Abstract

Managing Threats to Small Drinking Water Systems in Ontario: A Risk Based Approach

By: Wendy Johnson

**Environmental Applied Science and Management, 2007
Master of Applied Science, Ryerson University**

Ultimately the goal of Justice O'Connor's recommendations from the Walkerton Inquiry was "to ensure that Ontario's drinking water system deliver water with a level of risk so negligible that a reasonable person would feel safe drinking the water" (O'Connor, 2002a, 5). Following the implementation of Justice O'Connor's recommendations, concerns were raised regarding the management of small drinking water systems using the same stringent rules that were used for municipally-run water systems. Recommendations have focused on the need for risk assessment when managing the threats to small drinking water systems; however no such system has yet been developed in Ontario. A risk-based approach has been developed that would ensure drinking water protection activities are targeted to items that pose the greatest risk to water systems, resulting in more efficient protection efforts. The creation of such a risk-based program can be used to accurately identify significant threats to a water system and result in the effective management of health threats from small drinking water systems.

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Chapter 1: Introduction

1.1 Background

Safe drinking water has been a foundation of public health since Dr. John Snow's epidemiological work with the Cholera epidemics in England. In August 1854, Cholera rapidly spread through Broad Street in the Soho district of central London. The outbreak caused over 500 deaths in only 10 days (Hrudey, 2004). Snow was studying the relation between water and disease and correctly postulated that the water supply had been contaminated and was the source of illness. Snow was able to link the cases to the Broad Street water pump through meticulous data keeping and had measures put in place that would control the spread of disease (Newsom, 2006).

Proving the connection between contaminated drinking water and disease was a critical step in preventative medicine. Public health initiatives have since become entrenched in the protection, treatment and detection of contamination in drinking water supplies. Many of the issues that surrounded drinking water in the nineteenth century are still a concern today, including whether the evidence linking disease and water is enough to take preventative actions. Debates continue about what the most effective form of prevention is and how much preventative action should be taken. Although many years have passed since society struggled with typhoid and cholera, today the struggle exists with newly emerging pathogens such as *E.coli* O157:H7 and *Cryptosporidium*.

In the developed world, providing safe clean water to the public is not constrained by a lack of knowledge, yet disease rates are surprisingly high. Although the true incidence of waterborne disease can only be guessed at, Morris and Levin (1995) estimate current disease reporting is well under the true rate. Morris and Levin speculate that approximately 520 000

cases of moderate to severe disease occur in the United States each year. In a comprehensive study, conducted by Craun (1992), of reported waterborne outbreaks from 1920 to 1990 in the United States, Craun found that 1 702 waterborne outbreaks had caused 542 018 cases of illness and 1 089 deaths related to water contamination. Although the true rate of illness from drinking water can only be estimated, conservative data indicate that Canada and North America are suffering from waterborne disease outbreaks at a startling rate.

The impact of waterborne illness on society is staggering, yet it could easily be prevented. History has shown water systems that are believed to be safe and well managed are proven to have obvious and deadly faults. At the start of the 21st century, Canada's water utilities were at an increased risk for waterborne outbreaks because of the lack of protection measures in place and the complacency regarding the management and protection of drinking water (de Loe and Kreutzwiser, 2005).

In 2000 and 2001, Canada experienced two major waterborne outbreaks, in Walkerton Ontario and North Battleford Saskatchewan, with each outbreak resulting in significant illness and a public inquiry. The Walkerton Inquiry called on Ontario's government to institute more stringent drinking water laws, regulations and policies. The provincial government responded by creating the *Safe Drinking Water Act 2002* and two regulations specifically geared toward public drinking water supplies, *O. Reg 170/03 Drinking Water Systems* and *O. Reg 252/05 Non-residential and non-municipal seasonal residential systems that do not serve designated facilities*.

After the implementation of these regulations, the Ontario Government realized that the protection of drinking water supplies is not an easy task and that different water systems require different approaches to be managed effectively. The Ontario Drinking Water Advisory Council

(ODWAC, 2005) has noted that small drinking water systems¹ cannot be managed by the same rules governing municipally-run water systems. Furthermore, the Council recommends that small drinking water systems must be managed using a risk based approach in order to ensure risks are dealt with in order of importance.

1.2 Research Question and Hypothesis

Can significant threats from small drinking water systems be accurately predicted, characterized and appropriately managed so that the risks to drinking water are reduced to a negligible level?

Ultimately the goal of Justice O'Connor's recommendations from the Walkerton Inquiry was "to ensure that Ontario's drinking water system deliver water with a level of risk so negligible that a reasonable person would feel safe drinking the water" (O'Connor, 2002a, 5). Following the implementation of Justice O'Connor's recommendations, concerns were raised regarding the management of small drinking water systems using the same stringent rules that were used for municipally-run water systems. The original approach required that small water systems, which service community centers, churches, restaurants, etc., meet the same requirements that a system supplying water to a large community must meet (Abouchar and Elliot, 2004, 16).

The Ontario Drinking Water Advisory Council (ODWAC, 2005) recommended the use of a risk-based approach to managing small drinking water systems and suggested that the management of such a system be under the jurisdiction of the local Boards of Health. The risk-based approach would ensure that drinking water protection activities are targeted to items that pose the greatest risk to water systems, resulting in more efficient and cost effective protection efforts. This thesis proposes a pilot study in developing a risk-based approach for managing

¹In the context of this study, a small drinking water system is defined as a privately run water system that serves a public facility.

small drinking water systems in Ontario. It is hypothesized that the creation of such a risk-based program can be used to accurately identify significant threats to a water system and result in an improvement in the management of health threats from small drinking water systems.

1.3 Purpose and Objectives

This study proposes a pilot risk assessment and risk management tool that can be used by health professionals to assess the risk posed to a water system and identify possible control measures to manage these threats. The ultimate purpose of this pilot study is to enhance the research on risk assessment and risk management in drinking water. This study could lead to an improvement in the management of small drinking water systems and possibly to a decrease in the number of waterborne outbreaks from small drinking water systems across Ontario. The principle objectives of this study are:

1. *To conduct a preliminary review of past reports of waterborne outbreaks throughout Canada and the United States in order to assess the predominant causes of failure among all water systems.*

The purpose of this objective is to assess the predominant causes of failure leading to waterborne outbreaks. The assessment of previous failures in water systems will be a key factor in characterizing significant threats to the water source.

2. *To assess the feasibility of identifying critical points in small water systems where control measures could be instituted that would prevent or reduce the risk of an outbreak occurring.*

The purpose of this objective is to provide a framework that professionals can use to identify critical control points in the water system where protection measures should be

instituted. This examination is intended to provide guidance in assessing a water system and is based on historical water system failures that resulted in waterborne disease outbreaks.

3. To create a risk management framework that will assist decision makers with managing identified risks to a water system.

The purpose of this objective is to provide a methodical approach to identifying threats to a water system and dealing with them using a risk management approach.

1.4 Organization

This thesis is composed of five chapters, which are laid out as follows. *Chapter Two: Understanding Waterborne Outbreaks* provides a detailed look at the causes of waterborne outbreaks, beginning with the components of a water system, the organisms of concern and trends in past waterborne outbreaks. It also details the history of drinking water legislation in Ontario, with a specific look at small drinking water systems. *Chapter Three: Risk Assessment and Drinking Water*, discusses the key concepts of appropriate water system management from the multibarrier approach to risk assessment. This section examines the use of risk assessment to accurately identify hazards to small drinking water systems and provides a discussion of possible hazards to small water systems. *Chapter Four: Drinking Water Management*, presents a risk management tool for small drinking water systems using decision making techniques, and provides example applications of this method. Lastly, *Chapter Five: Conclusions and Recommendations* discusses the possible application of this research and identifies areas for further research.

Chapter 2: Understanding Waterborne Disease Outbreaks

2.1 The Drinking Water System

Water systems normally consist of three steps: a water supply, treatment methods and the distribution system. Drinking water constantly faces threats of contamination and can be protected by implementing control measures at each of the three steps in the water system. The water source must be protected from source contamination, water must then be treated by an effective treatment method, and lastly the distribution system must be maintained to ensure contamination does not reenter the water system.

Water supplies come from two sources: 1) surface water, which includes rivers, streams and lakes, and 2) ground water, which is subsurface water, found between saturated soil and rock that supplies water to wells and springs. Both ground water and surface water can become contaminated by urban run off, run off from neighboring farms, septic spills, or industrial activities. It is generally believed that ground water supplies are more protected from such contamination than surface water (Twort et al., 1997). As water travels through the soil bacteria and viruses are filtered from the water supply. However if wells are shallow, soil is poor, or the well-casing is leaky, pathogens or other contaminants can pass directly into the water supply.

Water supplies that are impure require that the water undergo treatment before it is safe to drink. The treatment system removes contaminants from the water supply. Water treatment methods might include one, or a combination of the following methods: screening, sedimentation, aeration, coagulation and flocculation, clarification, sand filtration and chlorine disinfection (Binnie, 2002, 26). Water treatment methods must be selected based on the microbial, chemical and physical quality of the water to ensure key health parameters are met

(AWWA, 1995). Sedimentation, filtration and disinfection are the three elements of the traditional water treatment processes and will be elaborated upon below.

The sedimentation/ clarification process includes coagulation, flocculation, and sedimentation (Binnie et al., 2002, 26). This process removes organic material, silt and sand, colloids, suspended particles and dissolved solids from the water. These fine suspended solids can cause water turbidity, a key water-quality parameter for ensuring the safety of drinking water. Bacteria and viruses attach to suspended particles in drinking water; when particles settle, viruses and bacteria can be removed. Sedimentation has been shown to provide a ½ log Giardia removal and 1 log virus removal in drinking water (Spellman 2003, 473). The presence of solids in water can also act to protect pathogenic organisms from both chemical and UV disinfection. Disinfecting a turbid water supply can be less effective when organic materials are present, by increasing the demand on chlorine resulting in less free available chlorine to inactivate pathogenic organisms in the water (Binnie et al., 2002, 215). In addition, increased turbidity can block UV rays from reaching and effectively destroying pathogenic organisms in the water supply.

Granular filtration also plays an important role in removing bacteria and viruses from drinking water by reinforcing the sedimentation process. Granular filtration passes water through a bed of sand to remove suspended particles; however, the filtration process is more complex than a simple straining technique; it uses five key principles, which are 1) interception, 2) sedimentation, 3) diffusion, 4) hydrodynamic action, and 5) inertia (Binnie et al., 2002, 139) [please refer to appendix 2.1 for a detailed description on the mechanics of filtration]. As water passes through the filter these principles facilitate the removal of foreign material from the water, including harmful materials such as bacteria and viruses. The three processes coagulation,

filtration and sedimentation when combined can remove up to 98% of suspended particulates (Twort, 1997, 232). However, granular filters cannot protect the water supply from harmful pathogens such as *Cryptosporidium parvum* oocysts (Spellman, 2003); newer filter technology is required to provide greater protection from such pathogens.

New treatment technology such as membrane filtration, ozonation, and sensing devices may provide ways to meet these health threats. Membrane filters employ ultra filtration, micro filters, reverse osmosis and nano filtration to separate organic and inorganic contaminants from the water (N.A., 2003). In addition to removing microorganisms and their oocysts, these filters also remove lead, nitrates, iron, and manganese. Studies have shown that membrane technology is considerably more effective than traditional sand filtration (Lipp et al., 1998 and N.A., 2003), however it is not widely used in treatment plants, primarily due to cost.

Disinfection is the final and most critical point in water treatment. Spellman (2003, 487) states that 46 percent of outbreaks in public water supplies are related to deficiencies in source water and treatment systems. Disinfection is responsible for killing all pathogenic organisms that have managed to pass by the sedimentation and filtration step. Disinfection controls waterborne disease and provides a residual disinfection that protects the water supply during distribution (Spellman, 2003).

There are a variety of disinfectants for use in drinking water including chlorine- the most common and widely used disinfectant, ozone, chlorine dioxide, and UV light. In order to be effective all disinfectants require a specific contact time, temperature, and concentration (WHO, 2003, 169). Although chlorination is considered to be “the single most important process for preventing the spread of disease” (Spellman, 2003, 501) there are some concerns around its use. Chlorine can react with organic and inorganic material to create a by-product known as

trihalomethanes (THMs) a carcinogenic compound (Sullivan et al., 2005, 96). The discovery of THMs has increased the importance of adding chlorine reliably to drinking water. Chlorine must be appropriately dosed in order to kill pathogenic organisms and maintain residual levels of chlorine while ensuring THMs are reduced. Prior to the identification of THMs, chlorine was commonly added to water at the beginning of the water treatment process, which resulted in high THMs levels due to the presence of organic materials. Practices have re-focused the importance of clarification and filtration to remove the majority of organics before disinfection in order to reduce the creation of THMs.

Some communities have been so worried by the production of THMs that they have chosen not to treat their drinking water, which has resulted in waterborne outbreaks. Creston Erickson, B.C. experienced two outbreaks of Giardiasis due to a lack of treatment of the water supply (Hrudey S. and Hrudey E., 2004). The first outbreak occurred in 1985 resulting in 83 cases of illness and the second outbreak occurred in 1990 resulting in 124 cases. The town received its drinking water from Arrow Creek, a surface water supply that was unfiltered and unchlorinated. An investigation into the second outbreak found that the water supply was being contaminated upstream by an infected beaver. After the second outbreak the provincial government attempted to take control of the water supply and implement chlorination; however, the local Water Action Group (WAG) set up a blockade on the road that lead to the water intake; the blockade was comprised of 200 volunteers and lasted 55 days. WAG claimed that chlorine was a danger to the health of consumers causing cancer, miscarriages and birth defects. In the end the province made a compromise with the town's citizens. The water treatment system now consists of membrane filtration and UV disinfection; chlorine is added only as a residual for the distribution system (Hrudey S. and Hrudey E., 2004).

The final step in the water system is the distribution system. This system moves water through a network of distribution mains, service pipes, reservoirs and pumping stations.

Distribution systems are a key part of the water system. Water producers must ensure that the same high quality water that leaves the treatment plant reaches the consumers tap. Failures in the distribution system can be a result of cross connections, back siphonage, open supply reservoirs, or a breach in the distribution system line (AWWA Research Foundation, 2001). Once microorganisms enter the water supply they have the ability to rapidly replicate and contaminate the water supply.

Today the responsibility of providing safe drinking water to consumers does not start and stop at the treatment plant, but begins at the water source and ends at the consumers tap. Although the water system has been discussed as three components, the water supply, the treatment system and the distribution system, not all water systems have water treatment. The majority of private wells do not have treated water, and in many cases small water systems such as restaurants, hotels or campgrounds, which serve the public, fail to treat their water (ODWAC, 2005). Unfortunately, water supplies are rarely pristine and often require treatment in order to render the water safe to drink.

2.2 Contaminants in the Water Supply

The water supply can become contaminated by chemical, microbial or physical hazards. Microbial pathogens pose the greatest risk to drinking water safety (Hrudey S. and Hrudey E., 2004, 395) because such organisms are always present in the environment and constantly challenge water systems. Microbial hazards can exist in three forms: bacteria, viruses, and parasites- also referred to as protozoa. Microbial pathogens enter the water supply through

human or animal sewage; such contamination commonly causes enteric illness in humans. Understanding the characteristics of these pathogens is critical to their control in the water supply.

Bacteria

Bacteria are the smallest independently living cells. Their size ranges from 0.25-3.0 micrometers, and they exist in one of three shapes: spherical, rod or curved (Jensen, Wright and Robinson, 1997). Bacteria can be found in almost all media that can support life, including the water supply. Most bacteria are harmless and do not pose a threat to the safety of drinking water, but some bacteria are pathogenic and when ingested can cause illness in humans. Bacterial organisms that have been known to cause waterborne disease include *Campylobacter jejuni*, *Vibrio cholerae* (cholera was common in the 19th century but fortunately is no longer a threat in the developed world), *Escherichia coli* O157:H7, *Salmonella* and *Shigella*.

E.coli O157:H7 is of particular interest because it is a relatively new pathogen and it has been known to cause very large outbreaks and death (Doyle, 1991). Various non-pathogenic strains of *Escherichia coli* have been widely used as fecal indicator organisms. However, since 1982, the pathogenic strain *E.coli* O157:H7 has been identified as the cause of hemorrhagic colitis in children and the elderly. The source of *E.coli* O157:H7 is often related either directly or indirectly to cattle. The first well-known cases of illness from *E.coli* O157:H7 were in 1982 from eating undercooked beef (Doyle, 1991). This strain of *E.coli* has also been associated with waterborne outbreaks. The first waterborne outbreak strongly linked to *E.coli* O157:H7 occurred in Missouri in 1989 (Hunter, 1997). The town's water was untreated and supplied by a deep well. The investigation discovered that the water supply had become contaminated when a water main broke in conjunction with a sewage overflow. Sewage entered the water supply through

the main break and since the water was untreated, it was susceptible to contamination. The outbreak resulted in the illness of approximately 243 people and four deaths. *E.coli O157:H7* was also responsible for the illness of 2300 people and 7 deaths in Walkerton Ontario in 2000 (O'Connor, 2002a).

Protecting the water supply from pathogenic bacteria can be done with simple water treatment techniques. Bacteria can easily be removed from the water supply because of their relatively large particle size and because most forms of bacteria are readily destroyed by chlorine-based disinfectants (Hrudey S. and Hrudey E., 2004, 24).

Viruses

In drinking water viruses are inert organisms that, once ingested can replicate and cause harm to the host. Viruses contain no independent metabolic activity; they consist of a small amount of genetic material and a protein coat. Viruses range in size from 20 to 300 nanometers (Jensen, Wright and Robinson, 1997). When a virus is ingested by a host, the virus becomes activated and will infect the host. Viruses that are commonly transmitted through drinking water include Rotavirus, Hepatitis A and the Norwalk-like virus (recently classified as "Norovirus").

Norovirus is believed to cause a significant number of gastrointestinal illnesses. It is estimated that this virus is the leading cause of gastroenteritis in the United States (Lindesmith, L et al. 2003). Norovirus is highly infectious and can quickly spread through food, water, or person-to-person. The viruses in the Norwalk group are extremely difficult to cultivate in a laboratory setting and are especially difficult to isolate from a water sample. It is believed that they may be the cause of many unknown cases of gastroenteritis. Often the agent responsible for waterborne disease cannot be identified; many studies (Craun et al., 1981; Lippy and Waltrip, 1984; Kramer et al., 1996) have found 40-50 percent of enteric illnesses are attributed to an

unknown cause. Norovirus is also highly resistant to disinfectants making protection measures difficult.

The removal of viruses from the water supply can be especially difficult. The small size of virus particles makes it difficult to remove them by traditional filtration and viruses are considered only mildly susceptible to disinfection. Communities that have a history of viruses in the water supply have used alternative treatment methods such as membrane filters or ultraviolet disinfection with great success (Aveni, 2001).

Protozoa

Protozoa are also commonly found throughout the environment. The majority of protozoa are benign but there are a small number that can cause disease in a human host. Protozoa commonly causing illness in North America include *Giardia lamblia* and *Cryptosporidium parvum* (Hunter, 1997). These protozoa have the ability to form cysts (containing a single parasite) or oocysts (containing multiple parasites) (Jensen et al., 1997). These cysts protect the parasite when faced with a challenging environment. Cysts are extremely hardy and can resist extreme temperatures and disinfectant. When a cyst is ingested, the protozoa will infect the host's gastrointestinal tract and cause gastroenteritis.

Giardia lamblia is the most common intestinal protozoan pathogenic infection in the United States (Craun et al., 1981; Kramer et al., 1996; Schuster et al., 2005). The cyst formed by the protozoa is able to survive for prolonged periods outside the body. Wild animals, especially beavers, are common carriers of *Giardia*; the protozoan cysts are often transmitted to humans by drinking untreated surface water. Hunter (1997) reports that studies have found cysts in 81% of raw surface water samples across the United States and in one Canadian province, indicating that untreated surface water has a high likelihood of containing such contamination.

Cryptosporidium parvum is extremely infectious with an infectious dose of only 30 oocysts (Dupont et al. 1995). Cryptosporidiosis is particularly dangerous in immuno-compromised patients where the disease is quite severe, lasting months and even causing death; this protozoan pathogen has also been associated with a number of very large outbreaks. *Cryptosporidium parvum* was the organism responsible for the largest waterborne outbreak in the United States in Milwaukee, Wisconsin, in 1993 (Solo-Gabriele and Neumeister, 1996). The outbreak affected approximately 403,000 people and caused the premature death of 69 people, most of whom were HIV positive. The investigation found that the source water was heavily contaminated with oocysts from an unknown source; however, no specific failure of the water treatment facility was present. High turbidity levels in the water were reported and believed to have increased the risk to the water supply but the treated water did comply with all of the federal and local requirements.

The removal of protozoa from the water supply requires extremely effective sedimentation, coagulation and filtration practices (AWWA, 1995, 14). Protozoa cysts are quite small in diameter, 2-50 micrometers, and will pass through an inefficient filtration system. Cysts are relatively resistant to disinfection and the disinfection process alone will not protect the water supply from contamination.

Pathogens are always present in drinking water. Understanding the microbial hazards in the water supply assists in characterizing and understanding the hazards inherent in the water supply, and plays an important role in identifying appropriate control measures that will protect drinking water.

2.3 Identifying Key Threats to the Water Source

The literature examining previous waterborne outbreaks (WBO's) is abundant. Waterborne outbreak summaries have been conducted regularly in the United States since 1971 by the Center

for Disease Control. These data have been used to compile and publish summary reports on outbreaks from drinking water. In Canada outbreak summaries have also been conducted with data gathered by Health Canada, but on a much less frequent basis.

The author conducted a review of

Figure 2.1- Waterborne Outbreaks examined by organism
Source: Appendix 2.2 compilation of waterborne outbreaks from 1974-2004

waterborne outbreaks reported in the literature

Figure 2.2 Seasonal Trends in WBO's

for Canada and the United States from 1974 to 2004. The examination revealed 215 detailed waterborne outbreak reports [refer to appendix 2.2]. These outbreaks were caused by microorganisms, and resulted in 456,000 illnesses and 15 deaths. *Giardia lamblia* was the most commonly identified pathogen in 44 of the outbreaks, whereas in 92 of the reports the causative agent was unknown [refer to figure

Source: Appendix 2.2 compilation of waterborne outbreaks from 1974-2004

2.1]. The data also shows a spike in waterborne outbreaks over the summer months- June July and August [refer to figure 2.2].

The key interest in the review of these data was to identify the predominant causes of failure leading to waterborne outbreaks. The primary causes of outbreaks were reported as treatment failure (47.4%), lack of water treatment (37.7%) and a failure in the distribution system (17.2%)

[refer to figure 2.3]. A paper by Schuster et al. (2005) examining drinking water outbreaks in Canada from 1974 to 2001 also found that failures of the treatment process and a need for greater treatment were the leading cause of outbreaks.

When examined by water source (ground water versus surface water) outbreaks in ground water sources were more commonly cited as being caused by

Figure 2.3 Factors Contributing to WBO's

Source: Appendix 2.2 compilation of waterborne outbreaks from 1974-2004

Figure 2.4 Contributing factors vs water source

Source: Appendix 2.2 compilation of waterborne outbreaks from 1974-2004

a lack of treatment, while in surface water, outbreaks were most commonly associated with treatment failures [refer to figure 2.4].

Studies of waterborne outbreaks, such as Craun, Calderon and Nwachuku's (2003, 116) study of previous waterborne outbreaks in the United States found that ground water without treatment or with interrupted disinfection was a leading cause of illness, challenging the general belief that ground water is safe and requires no treatment to protect it from contamination.

Examining waterborne disease outbreaks is essential to understanding the causes of outbreaks and instituting protection measures (Hunter, 1997, 34). Schuster suggested that understanding waterborne disease reports can provide policy makers with the information needed to identify the risks in water systems (Schuster et al., 2005). However, this summary of 215 waterborne disease outbreaks only represents a fraction of the true burden of illness from waterborne outbreaks. Low reporting rates and partial reports limit the ability to determine the true cause of water system failures.

It was also observed that investigators tended to cite only one failure as the cause of the outbreak. Waterborne disease outbreaks are complex in nature (AWWA Research, 2001, 150) and are often caused by multiple contributing factors, not a single catastrophic decision or action. For instance, in September 1999 the Washington County Fair in New York USA experienced a waterborne outbreak of *E.coli* O157:H7 and *Campylobacter jejuni*, resulting in 2 deaths and 2 800-5 000 illnesses (N.A., 2000). The Fair's water supply was provided by 6 wells, two of which were chlorinated. A drought preceded the fair, but on August 26th and 27th heavy rains fell. Reports of children in hospital for bloody diarrhea began on September 3rd. The outbreak was caused by multiple contributing factors, including wells that were located too close to septic

systems, unchlorinated water supplies and heavy rains which increased the risk of contamination reaching the water supply (Hrudey S. and Hrudey E., 2004). This outbreak demonstrates how multiple factors often interact to result in a waterborne outbreak. To prevent waterborne outbreaks and reduce the incidence of disease the true causes of waterborne outbreaks must be fully understood.

2.4 Drinking Water Management in Ontario

The most comprehensive report on the management or mismanagement of Ontario's drinking water was produced in response to the Walkerton Outbreak- the Walkerton Inquiry Reports (O'Connor, 2002a & 2002b). The Walkerton Inquiry was headed by Justice Dennis O'Connor and had two mandates (Abouchar, 2003). The first goal of the inquiry was to determine the cause of the outbreak, including the effects of government policy, practice and procedure. The second mandate was to examine the situation beyond Walkerton and develop a plan the government could implement to ensure the safety of drinking water across Ontario.

The first report was devoted to the events that occurred in Walkerton. Justice O'Connor (2002a) found that both physical sources and mismanagement had contributed to the outbreak. The physical cause of contamination was the presence of bacteria in the water and the lack of water treatment to ensure the water's safety. Heavy rainfall a few days before the outbreak had washed cow manure, from a neighboring field which contained pathogenic bacteria, to the head of the well. The well was poorly cased, and the bacteria entered it, contaminating the water. Furthermore, the municipal water operators in Walkerton, known as the Public Utilities Commission operators, did not add adequate chlorine to the water that would render it safe (O'Connor, 2002a, 5).

The broader cause of the outbreak was revealed as a failure in the regulatory system, resulting from government actions and inaction (O'Connor, 2002a). Prior to the Walkerton outbreak, water responsibilities were shared between the Ministry of the Environment and Public Health. The Ministry of the Environment was responsible for overseeing and regulating the operation of public water systems, while Public Health Departments were responsible for delivering the Safe Water Program of the Mandatory Health Programs and Services Guidelines (Ontario Ministry of Health, 1997), which defined their role in terms of reactionary responses, such as responding to adverse water results and issuing boil water advisories.

From 1992-1995, the provincial government significantly cut the Ministry of the Environment's (MOE) and the Ministry of Health's budget. After a change in government in 1996, the budget underwent further cuts- the MOE budget suffered 200 million dollars in cuts from 1992-1999, along with a 30 percent staffing cut (O'Connor, 2002a, 34). The MOE's monitoring and enforcement abilities had been severely diminished and inspection frequencies drastically declined.

In 1996, when the government began making widespread funding cuts to public health services, numerous warnings were sounded that these cuts would have adverse results on the health of the public. Dr. Richard Schabas, Chief Medical Officer of Health at the time, stated that in a cabinet meeting in 1997 "[Harris has] turned his back on public health" (Perkel, 2002). However, nothing was done to rectify the lapse in funding.

The provincial government was strongly chastised by the Walkerton report for their inaction and withdrawal of services. After the release of the reports, the government quickly changed its priorities (Donnelly and Hagreen, 2002, 225). After Walkerton, from 2000 to 2001, all of Ontario's 600 water treatment plants were inspected. In order to regain public trust, the

government added more enforcement, money and inspectors to both the Ministry of the Environment and the Ministry of Health.

Part II of the Walkerton Inquiry conducted by Justice Dennis O'Connor identified a need for a more proactive approach to drinking water from the public health sector and it focused on developing a strategy to ensure Ontario's water was safe. Ninety-three recommendations emerged from the second report regarding all aspects of water protection. The goal of the recommendations, described by Justice O'Connor (2002b), read:

While it is not possible to remove all risk from a water system, the recommendations' overall goal is to ensure that Ontario's drinking water system deliver water with a level of risk so negligible that a reasonable person would feel safe drinking the water (p.5).

A multi barrier approach was suggested in the creation of the recommendations. This means water would be protected from contamination at each step, from 'source to tap'.

One of the first official actions taken by the provincial government after the release of the Walkerton Reports was to create a stricter framework for the legislation of drinking water, by passing the *Safe Drinking Water Act (SDWA) 2002*. Two regulations were also enacted under the *SDWA*; *O. Reg 170/03 Drinking Water Systems* which was developed first and later in response to an identified need *O. Reg 252/05 Non-residential and non-municipal seasonal residential systems that do not serve designated facilities* was developed.

When *O. Regulation 170/03* came into force in June 2003, the regulation initially addressed the requirements for both large and small water systems to provide water to the public. The requirements under the Regulation are prescriptive and address the installation of treatment equipment, weekly water testing, reporting of adverse water samples and the training of the systems operator. In essence, this regulation required small water systems that service small

municipalities, community centers, churches, town halls, privately run motels, campgrounds, and mobile parks to meet the same detailed requirements that a system supplying water to a large community must meet (Abouchar and Elliot, 2004, 16).

Since *O. Regulation 170/03* came into force, it has been criticized as being overly restrictive. Small-scale operators and small municipalities have been economically challenged by the requirements of the regulation and many cannot afford to meet them. Abouchar and Elliot (2004) note “A number of community centers and rural churches have turned off their taps because they cannot afford to comply with the new requirements of the Safe Drinking Water Act (SDWA) and its regulations” (p.16). The cost of meeting the requirements of *O. Regulation 170/03* is estimated to be 10,000 to 20,000 dollars initially, followed by 5,000 dollars in yearly operation costs (ODWAC, 2005, 51). It is thought that small system operators are just hoping the fines for non-compliance are less than the cost of the treatment device (Abouchar and Elliot, 2004).

In 2004 the Advisory Council on Drinking Water Quality and Testing Standards (ODWAC) was requested to analyze the cause of the problem and develop recommendations to address these issues. In the Council’s analysis they stated:

...the Regulation [*O. Regulation 170/03*], as it applies to smaller and private systems, is considered to be costly, complex and not well understood by the regulated community. These factors, and the resulting inconsistent interpretations, may lead to either non-compliance or a withdrawal of services to the public (ODWAC, 2005, 6).

The Council recognized *O. Regulation 170/03* was too encompassing and that there was a need to develop recommendations that would relax the Regulation; in essence, reduce noncompliance while still meeting Justice O’Connor’s recommendations (Abouchar and Elliot, 2004, 16).

The ODWAC (2005) concluded that the problems surrounding *O. Regulation 170/03* cannot be remedied through simple changes to the Regulation (ODWAC, 2005, 20). ODWAC felt the Regulation was effective for large water systems that had the revenue base to support the requirements. However, they recognized that it was impossible for all small water systems to meet the same requirements. ODWAC (2005) proposed a number of solutions. The first being that the MOE remove all small water systems from *O. Regulation 170/03* and create a separate regulation to address small water systems. ODWAC (2005) commented, “Generally speaking, owners/operators do not understand which category they fall under, and more importantly, what rules they have to follow in order to be in compliance” (p.32). By separating the regulation of small and large systems, confusion could be avoided. This recommendation was acted on at the beginning of 2004 and resulted in the creation of *O. Regulation 252/05*.

A second recommendation from ODWAC (2005) has been to transfer the responsibility of monitoring and enforcement to Public Health Units. This means that public health inspectors would administer safe water programs for all commercial and institutional systems that serve the public and that *O. Regulation 252/05* would be under the *Health Protection and Promotion Act* instead of the *Safe Drinking Water Act 2002*. Involving public health departments to administer small water system programs will bring drinking water management back into the hands of the local Health Departments.

The health department’s role will be less reactive and more proactive. The Council proposes, “a risk based site-specific approach” (ODWAC, 2005, 36) to small water systems. A risk-based approach can decrease the likelihood of contaminants reaching the water supply by proactively identifying potential sources of harm. A risk-based approach would transfer the responsibility of assessing the risk of all commercial and institutional water systems that serve

the public to Public Health Units. Employing such a risk-based method may alleviate some of the difficulties involved in ensuring the safety of the water supply. Yet, as of November 2007 these management changes have not been implemented.

Chapter 3: Risk Assessment and Drinking Water

3.1 The Multi-Barrier Approach

Following the Walkerton waterborne outbreak, the Inquiry reports by Justice O'Connor called for the safety of Ontario's drinking water by using a multi-barrier approach to protect the water supply. Many scholars responded to this call by describing/developing management techniques based on the multi-barrier approach that would reduce the risk from drinking water systems (Hrudey S. and Hrudey E., 2004; Huck and Coffey, 2004; Krewski et al. 2002; Retallack, n.d.) including one management system developed and currently in use in the water industry.

A multi-barrier approach requires that once one part of the system is found to be weak, a more secure system be in place further down the line. For example, "a less secure water source that faces greater contamination challenges will require more robust treatment because of the correspondingly higher risk that is posed" (Hrudey et al, 2002, 398).

A multi-barrier system is composed of five factors, in which all five factors are necessary for a secure system. They are:

- 1) source protection- by protecting raw water from contamination, the risk of contamination to the drinking water supply is reduced
- 2) treatment- the process used to remove or inactivate contaminants
- 3) distribution system- ensuring contaminate intrusion and disinfection residual deliver safe water
- 4) monitoring programs- should control the treatment process and detect contamination
- 5) responses to adverse conditions- should be well planned, thorough and effective

(Hrudey S. and Hrudey E., 2004)

A multi-barrier approach ensures safety measures exist at all points in the water system.

A comprehensive study by Hrudey S. and Hrudey E. (2004) collected and published reports of waterborne outbreaks from across the globe in order to call attention to the full range of possible failures in the water system and to provide a perspective, to water operators and professionals, on the nature of drinking water outbreaks. Hrudey S. and Hrudey E. (2004, 395) concluded that:

robust, effective multi barriers to drinking water contamination are needed to suit the level of contamination challenge facing the raw water source” and that “ensuring safety is an exercise in risk management requiring sensible decisions in the face of uncertainty.

Huck and Coffey (2004) found that when the Walkerton outbreak was analyzed based on the principles of robustness², there was a lack of robustness in both the physical and organizational components. This multi-level failure allowed the water system to become vulnerable and to result in such a large outbreak. Huck and Coffey (2004, 1589) concluded that improving the robustness is a prerequisite for improving the water supply, and “improving robustness therefore provides a goal for water utilities and a quantifiable basis for continuous improvement”.

Large municipal water systems in Ontario have begun to implement a management approach that ensures a robust water system through the continual improvement of the water supply. The Ontario Ministry of the Environment (2006) drafted a guidance paper for drinking water utilities termed ‘The Drinking Water Quality Management System’ (DWQMS). The DWQMS is a mandatory management element designed to license municipal drinking water under the *Safe Drinking Water Act 2002*. The DWQMS contains key components from quality management systems, such as ISO 14001 and HACCP in one integrated management system. The purpose of the management system is:

¹ Robustness is the ability of a system to cope with changes or pressures without failure.

- 1) to demonstrate the operating authority's ability to consistently produce and/or deliver drinking water that meets applicable regulatory requirements
- 2) to demonstrate the operating authority's ability to consistently produce and/or deliver drinking water that meets applicable owner requirements
- 3) to enhance consumer protection through the effective application of the QMS
- 4) to provide for continual improvement of the QMS

(MOE, 2005, 1)

The DWQMS is especially relevant to ensure the water industry meets all applicable regulatory requirements, that the industry produce a product that meets consumer's requirements and that they continually improve to ensure they are prepared to handle future threats.

The Regional Municipality of Durham implemented such a program in 2004, prior to it becoming mandatory. Durham reported that the system has fostered good benchmarking practices, created a due diligence position, improved public confidence, and provided a continuous improvement process (Kuslikis, 2005). This system has been designed for large municipal water systems and requires a team to create and implement a HACCP plan.

3.2 The Risk Assessment Approach

Steven Hrudey (2004) notes that in developing a quality management standard in Ontario, it has developed:

a narrow set of detailed requirements related to specific water quality issues which will not be able to provide sufficiently comprehensive and flexible guidance to cover the diversity...that exists across Ontario (1557).

The multi-barrier approach is not ideal for all water systems. Small water systems may not be able to install all of the best protection measures because of financial or service barriers. For example, the usefulness of water testing is limited and becomes expensive when multiple tests must be done each week if the true quality of the water is to be reflected in the tests (McQuigge, 2002).

In 2004 the Advisory Council on Drinking Water Quality and Testing Standards (ODWAC, 2005) examined the legislation that was developed based on the multi-barrier approach and recommended the use of a risk-based approach to managing the water supply, explaining that it is a more practical approach to managing water systems specifically small water systems, because protection efforts and upgrades would focus on the item(s) of greatest risk while avoiding undue pressure on the operator to meet these requirements. This approach is based on preventative protection measures.

A preventative approach to water safety would identify the risks to a water system and establish control measures in order to protect the water supply. Producing safe drinking water requires that priorities for protection be developed on the basis of risk, not on the basis of a hazard. A hazard is the potential to cause harm, while a risk is the probability of that hazard causing harm (Hrudey, 2004, 1559). Risk is often discussed in terms of the probability of an

event occurring and an estimation of its magnitude (Risk = Probability x Magnitude) (Kasperson et al., 1988, 112). Krewski et al. (2002, 1638) note that in order to apply a fair and consistent approach to protecting the water supply, one must consider the magnitude of the risk posed and the potential for harm.

The application of a risk-based approach to drinking water is currently being discussed around the globe. A workshop held in the Netherlands examined the relationship between risk assessment and risk management in water safety (Kiwa Water Research, 2003). The paper produced from this workshop discusses the use of a HACCP³ based approach to managing the risks associated with drinking water. The conclusions derived from the workshop were that there is a need for an objective, scientific basis for risk management decisions and that risk assessment and risk management should not be regarded as two separate steps in the process but should be harmonized. In order to carry this out, it will take a combination of HACCP and risk assessment to provide a framework for identifying which control measures should be put in place.

New Zealand has developed a risk assessment approach for small drinking water systems based on the principles of HACCP and since implementation, New Zealand officials have reported an increase in compliance rates from small drinking water systems (New Zealand Ministry of Health, 2002). In 1993, New Zealand underwent a complete restructuring of the public health management of drinking water. After the restructuring, officials realized that something had been missed. In 1998, of the water samples not meeting the standards, 99 percent were from small water systems. The New Zealand water systems were constrained by many of the same factors Ontario's small water systems face, including access to laboratories and the high cost of treatment and monitoring requirements.

³ Hazard Analysis Critical Control Points (HACCP) a management system that uses a systematic preventative approach to food safety.

The risk management approach was considered to be a key component by New Zealand officials, who ensure that “[t]his approach is complemented by a monitoring program, used as a final quality control, which also acts as a feedback loop and provides a trigger for remedial action where necessary” (ODWAC, 2005, 47). The result of the new system was an improvement in the country’s drinking water quality, and increased compliance with the legislative requirements that had changed in 1993. By 2000, 81 percent of the population was receiving drinking water that was compliant with New Zealand’s drinking water requirements (New Zealand Ministry of Health, 2002).

The New Zealand approach is a non-regulatory intervention to ensure that small drinking water systems provide safe drinking water. The approach is a systematic assessment of the water supply, treatment, storage and distribution (ESR Water Group, 2002). The water system is given a grade, where A is acceptable and E is completely unacceptable with a very high level of risk, and anything less than a C indicates that a barrier to prevent contamination is missing. New Zealand attributes the success of their approach to the use and consideration of the risks to public health, the local communities’ concerns as well as the costs and benefits associated with management measures.

In 2006, in the United Kingdom, new regulations to address private water supplies serving the public were developed sparking debate on the duties for local authorities and risk management strategies (Stanwell-Smith, 2006). To support any risk based protection measures taken in the future research has begun at seven sites to assess the potential for contamination of the water supply in various circumstances, such as extreme rainfall.

While the above-mentioned studies have discussed the principles of a risk assessment for drinking water and the need for a flexible approach when examining small drinking water systems, there has not yet been the development of such a system in Ontario. The DWQMS, discussed above, has been created for large water systems; however, due to its large capacity and multi-barrier approach it is not practical for small water systems. The New Zealand approach has been developed for small water systems and could provide valuable guidance for a risk based system in Ontario. In the following section the author has produced a risk assessment framework that can be used to identify hazards present in small drinking water systems.

3.3 Proposed Risk Assessment Framework

In the Walkerton Inquiry Justice O'Connor (2002b) recognized that it is impossible to obtain zero risk in a drinking water system. Keeney (1995, 628) notes that "there are no risk free alternatives pertaining to any activity, process, or product" but the risks of greatest significance should be managed in order to reduce the overall level of risk. The use of risk assessment to manage small drinking water systems must identify parts of the system that are at the greatest risk of failure, also known as Critical Control Points⁴ (CCPs). CCPs exist where controls can be instituted to ensure a failure does not occur that would result in a significant harmful event (Krewski et al., 2002).

Identifying CCPs classifies which hazards are the greatest concerns in order to focus attention and resources on these areas. CCPs can be distinguished from common hazards by asking the question: "will a subsequent step in the process reduce or eliminate the risk?" (Canadian Food Inspection Agency (CFIA), 2007, Form 8). If a step further on in the process

⁴ CCP is a term used in HACCP. CCP is defined as "any point, step or procedure at which control can be applied and a food safety hazard can be prevented, eliminated or reduced to an acceptable level" (CFIA, 2007, 4.7.1)

will eliminate the hazard, control measures may not be required. If all hazards are treated equally, risk will not be managed because preventative efforts will be excessive for trivial risks and inadequate for substantive risks (Hrudey S. and Hrudey E., 2004, 79). For example, when wells have small leaks, suggested by constant low bacterial counts, a chlorination unit is often installed to reduce the threat from source water contamination, rather than repairing or replacing the well.

Past failures in drinking water management have proven that certain practices are more hazardous than others. However, the types of scenarios that can lead to a drinking water outbreak can vary; every water system is different and faces unique threats (WHO, 2003). It is impossible to say that there is one measure, that when put in place, will reduce the risk of an outbreak occurring. Instead, each section of the water system must be examined to identify the greatest risks. The water system can be broken into five key components to assist in identifying risks present in the water system. They are:

1. the water source
2. water treatment
3. water operator & emergency response
4. the distribution system
5. water storage

The characteristics of the water system should be rigorously analyzed through each of these five components to identify areas where hazards may increase the risk of a waterborne outbreak occurring [refer to figure 3.1]. Figure 3.1 has been created by the author to assist professionals in identifying weaknesses in the water system. The questions/statements below each component should assist to identify areas of concern. When the section identifies a bold italic statement, the

user must ask the question- *will a subsequent step in the process reduce or eliminate the risk?* If not, a control measure should be put in place to reduce the risk to the water system.

cont...

There is no trained
water operator

There is a trained
water operator

Operator is certified

Operator has designated a back up

Accurate records are kept

Daily operating task for the water system is conducted
by the operator (chlorine residual)
Records are maintained that record peak flow,
disinfection contact time, residual disinfection,
turbidity, the amount of water being treated,
complaints, unusual events- storms

Are there any additional risks?

Are there any additional risks?

There is no adverse
event plan

There is an adverse
event plan

Emergency response plan exists for two types of
emergencies 1) events out of control the operators
control, 2) where an interruption of the system has
occurred eg. power outage

Notification list exists

Are there any return pipes that would permit water to
be recirculated into the well

There is the potential for cross connections to occur
with other water sources such as sewage
Distribution system is in poor condition and has the
potential for leaks or main breaks
Potential for back siphon age from other water sources
exists- Back flow preventers are installed any where a
connection to the system is made

Residual disinfection is not adequate to protect the
water supply from further contamination- must be
monitored
Pressure in the distribution system drops to zero or
negative

Are there any dead ends in the distribution system
Is there a horizontal separation of the water supply
pipes and the sanitary sewer pipes (2.5m)

Are there any additional risks?

Distribution system is in
poor condition

Distribution system is
in good condition

Residual disinfection is not adequate to protect the
water supply from further contamination

Storage tank is not protected from contamination (eg.
Covered)

Storage tank is lined

Water storage is not
protected

Water storage is protected

Are there any additional risks?

The Water Source

The quality of the water source is paramount to ensuring the safety of the drinking water. High quality source water reduces the risk associated with the water system and would require less treatment. The quality of the source water depends heavily on the land uses surrounding the source. Potential threats to the water source may include grazing livestock, wildlife, or sewage sources (Canadian Council of Ministers of the Environment (CCME), 2004). Sewage systems must be located specific distances from water sources in order to reduce the risk of contamination. The Ontario Building Code (Ontario, 1997) provides separation distances for septic systems and water sources to ensure the safety of the water source [which can be viewed in appendix 3.1].

Water sources can become contaminated by pollution sources and result in large scale outbreaks. North Battleford experienced a waterborne outbreak of *Cryptosporidium parvum* in 2001 due to poor source water quality (Laing, 2003). North Battleford's water supply was drawn from the North Saskatchewan River, which was known to be heavily polluted. In 1993 water sampling showed that fecal coliforms were as high as 150,000 per 100mL of water, and that the North Saskatchewan River exhibited *Cryptosporidium parvum* counts as high as any water supply in North America (Hrudey S. and Hrudey E., 2004, 318).

The North Saskatchewan River was at high risk for contamination; Saskatchewan had never implemented a water protection plan to protect the water supply from surface runoff or other point contamination (Woo and Vicente, 2003, 261). Surface waters are easily contaminated through surface runoff and upstream discharges. The North Battleford's surface water plant was constructed only 3.5 km downstream of the cities sewage outfall. Studies conducted after the outbreak showed that the effluent from the sewage treatment plant upstream passed over the

water intake for the drinking water plant and increased the likelihood of contamination (Hrudey S. and Hrudey E., 2004).

The most secure water source is ground water that is not under the direct influence of surface water. Ground water is considered more secure because as water travels through the soil the soil filters microorganisms out of the water (Twort et al., 1997). Surface water and ground water under the direct influence of surface water should be considered contaminated (CCME, 2004) and require further treatment before they can be considered safe to drink. However, the best indicator of a water supply's quality is through microbial testing (WHO, 2003). Tests should be done regularly, and after severe weather such as heavy precipitation or drought, to determine the security of the water source. Such tests can show the true quality of the water when done properly.

Water Treatment

Failure to treat drinking water and failures in water treatment devices have been noted as the prominent cause of waterborne outbreaks by numerous studies (Craun et al. 2002; Lippy and Waltrip, 1984; Schuster et al. 2005). Treating water sources that are prone to contamination, or have a high risk of potentially being exposed to contamination is paramount; Krewski et al. (2002) note that the treatment process is the most critical step in the entire water system. Numerous outbreaks could have been prevented with simple water treatment devices, especially in small water systems. For example, in 2002 a camp in Connecticut experienced an outbreak of 142 cases of Norovirus (Center for Disease Control, 2004). The water supply was untreated and when heavy rains fell, the water supply became vulnerable and contamination resulted. The outbreak ended two days after chlorination of the water supply began.

Failure in water treatment can also be a common cause of outbreaks. Mechanical failures of the system are possible and require regular maintenance and a trained operator to oversee the system; however, all water treatment devices are not equal. The reliability of the device and the type of contamination can alter its effectiveness [refer to table 3.1 below]. It is important that the right treatment method is chosen based on the risks present.

Table 3.1 Effectiveness of Disinfectant Techniques on Pathogens

Disinfectant	Microorganism		
	<i>E.coli</i>	<i>Giardia</i>	<i>Cryptosporidium</i>
Chlorine	Very Effective	Effective	Not Effective
Ozone	Very Effective	Very Effective	Very Effective
Chloramines	Effective	Not Effective	Not Effective
Chlorine dioxide	Very Effective	Very Effective	Effective
Ultraviolet radiation	Very Effective	Very Effective	Very Effective

Canadian Councils of Ministers of the Environment, 2004, 128

The Water Operator

In Justice O'Connor's report (2002b) on the Walkerton outbreak he noted that there was a need to train water operators across Ontario. The operators of water systems are responsible for maintaining and ensuring the water treatment processes are working correctly. They play a critical role in the operation of the treatment system. Water operators must be certified, keep accurate records on sampling, maintenance, disinfection residuals, daily operating tasks, disinfection contact time, the amount of water being treated and any unusual events, such as storms (CCME, 2004, 133). The operator should also designate a back-up so when they are away the operation of the water system is not jeopardized.

Emergency response planning is also part of the operators' responsibility (CCME, 2004). An operator should have written plans for events that are not within the operator's control such as heavy rains, at which time chlorine residual and microbial testing might be increased, or when

there has been an interruption in the system such as a power failure. In such an instance chlorine may have to be added to the water manually or a boil water advisory issued until the water supply is considered safe.

The Distribution System

The distribution system is exceptionally vulnerable to contamination because there is no further step in the process that will remove contamination. Many outbreaks associated with the distribution system have occurred due to contamination entering the system after safety measures have been taken (Craun and Calderon, 2001). In 2004, in Montana, a restaurant's water supply caused 70 people to become ill with *Salmonella typhimurium* (Center for Disease Control, 2006). Investigators found that the distribution system contained cross-connections from the restaurant's water supply to the pipes that supplied water to the poultry pen located behind the restaurant. They concluded that there was most likely a backflow of water from the farm supply to the restaurant's potable supply.

Possible threats to the distribution system are anything that may allow contamination to enter the system including old pipes that have the potential to leak or break, dead end sections where water is stagnant and cross-connections that create the possibility for back siphonage from non potable water sources (CCME, 2004, 129). Backflow preventers should be installed at every connection to the water system to reduce the chance that non potable water will enter the system. Lastly, residual disinfection should be adequate to protect the water supply in case contamination does re-enter the distribution system and to prevent the re-growth of microbial contaminants (CCME, 2004, 129). Protecting the distribution system requires testing and monitoring of the water supply at all stages of the system; water must be tested prior to entering the plant, once leaving and also along the distribution path (Means et al., 2006).

Water Storage

Drinking water that is stored prior to use must have a residual disinfection that is adequate to protect the water supply from contamination should it enter the system and storage tanks should be lined and covered to prevent contamination from entering the water supply (CCME, 2004, 114). Contamination at the water storage tank has been known to cause large outbreaks, for example in Gideon Missouri in 1993, the City's water supply was contaminated with bird droppings while being held in an open reservoir (Angulo, et al, 1997). When these conditions combined with an untreated water supply, 650 people became infected with *Salmonella typhimurium* and 7 people died.

In addition to the risks mentioned above, risk identification should always ask: are there any additional risks? Every water system is unique and what is not considered a risk in one system may be a significant risk in another system. Risk identification is only one step in the process of managing waterborne threats; once the risk identification process has been completed, decisions must be made that will adequately reduce or remove the risk.

Chapter Four: Risk Management and Decision Making

4.1 Risk Management

Risk management is the process of recognizing risks and developing strategies to manage them. Hrudey (2004, 1559) notes that the essential characteristics of risk management are: (1) being preventive rather than reactive; (2) distinguishing greater and lesser risks and dealing with them in order of importance; (3) learning from past experiences; and (4) investing resources in risk management that are proportional to the risks that are posed.

A management framework for small drinking water systems is best described by examining the components of both risk assessment and risk management [refer to diagram 4.1]. Risk assessment provides the groundwork for risk management; however, risk assessment is not able to dictate a single correct course of action to take (Hrudey, 2004, 1560). Making the decision requires a review of the information gathered during the risk assessment and an examination of all the options available.

Keeney (1995) notes that managing risk must be done through an informed decision making process. Problems must be well understood and the process of solving them should be open and consistent. The best way to address risk is to acknowledge

Figure 4.1- risk assessment and risk management for small drinking water systems

the risk, clarify the objective, identify the role of judgments, and be consistent with how to deal with them (Keeney, 1995).

4.2 Making Decisions under Uncertainty

Decision making in public health is often based on imperfect and uncertain evidence. Making decisions under uncertainty is difficult because one cannot examine the outcome of the decision prior to making it (Holloway, 1979). Water system analysis has an inherent level of uncertainty when attempting to quantify the probability of an adverse event occurring. The uncertainty associated with small drinking water systems requires that a process or framework be used to assess decision choices.

4.3 Decision making criteria and setting critical limits

Krewski et al. (2002, 1642) notes that decisions must be based on options that are feasible with benefits that are reasonably related to their costs and give priority to preventing risks as well as controlling them. A trade-off table has been developed by the author of this thesis, that can be used to list alternatives and identify dominant choices once the evaluation criterion has been set [refer to table 4.2]. Table 4.2 provides a framework for the decision maker to identify all alternatives and set criteria to judge the alternatives in a simple yet inclusive way. As CCPs are identified using figure 3.1, a trade off table identifying alternative solutions would be created for each identified CCP.

CCP 1- (description)

Alternatives	Decision making criteria			Score
	Cost	Feasibility	Efficacy	
C _i	1-5	1-5	1-5	1-25

Table 4.2 Trade-off table

Risk management always involves trade-offs (Holloway, 1979; Hruidey, 1996). In order to make an informed trade-off each alternative must be evaluated based on the decision-making criteria, which have been defined below:

I. *Cost*- the monetary cost to the water operator.

This criterion is rated on a scale from 1-5 based on the description below:

5 = No Cost

4 = Minimal Cost- cost can be paid for as part of the annual cost

3 = Moderate Cost- can be paid for without excessive hardship

2 = Considerable Cost- can be undertaken but requires extra funds

1 = Beyond Capability- unable to afford unless significant funds are found

II. *Feasibility*- the ability to institute the measure based on space, technological requirements and human resources.

Feasibility is also rated on a scale from 1-5 based on the description below:

5 = Minimal Impact- implemented easily with minimal interruption or problems

4 = Minor Impact- implemented with relatively minor disruptions or difficulty

3 = Moderate Impact- implemented with moderate disruption or changes to the system

2 = Considerable Impact- implemented with considerable complications and changes to the system

1 = Extensive Impact- implementation is beyond the ability of the system
without major restructuring of the operation

III. *Efficacy*- the ability to produce the desired effect i.e. to prevent water contamination.

This criterion is also rated on a scale from 1 to 5 based on the descriptions below:

5 = Optimal- meets or exceeds all objectives in solving/preventing the issue

4 = Meets most objectives in solving/ preventing the issue

3 = Meets minimal objectives in solving/ preventing the issue

2 = Meets only short-term objectives in remedying the issue, with no long-term solution

1 = No change in protection level

It must be noted that there will be uncertainties in assigning a value to each alternative since the decision maker will use their judgment when assigning values. Once all options have been assessed the decision maker must identify the dominant alternative. To do this the values must be entered into the following equation:

$$\text{Efficacy} \times (\text{Cost} + \text{Feasibility}) / 2 = \text{Acceptability of the Solution}$$

This equation represents the key factors in making decisions for small drinking water systems. Efficacy is the principal factor for preventing possible failures of the system, which is represented by its weight in the equation. The other two factors- cost and feasibility will determine whether the proposed change will be implemented. The acceptability of the solution increases as the value increases; a cut off value of ten should be used in order to eliminate unacceptable choices. The equation above has also been represented in graph 4.3. Values that fall within the red and orange range should be discarded, as the value raises into the yellow and green regions the acceptability of the solution increases.

Graph 4.3 Decision Making using Trade offs
Efficacy vs. Cost Feasibility

Risk management frameworks provide objectivity, completeness and consistency of decisions and greater public accountability (Krewski, 2002, 1638). It is important that risk management frameworks identify areas of uncertainty, iteratively refine the problem and the analysis and are explicit about the decision criteria (Hrudey, 1996, 11). It is also critical that such decisions involve all parties, such as the owner and operators of the water system, government agencies, advisory groups and funding agencies. Each stakeholder will have varied opinions on weighting options or even identifying critical control points. By encouraging regulators to work in conjunction with the owner/operator of the water system, a balance should be obtained.

Three scenarios have been provided below which use the risk assessment and risk management tools discussed in chapters three and four to demonstrate how they can be used to assess a vulnerable water system and could have prevented the outbreaks that occurred.

Scenario 1- The Walkerton Waterborne Outbreak

The Water System:

In 2000 Walkerton received its water from three wells, Wells five, six and seven, which were run by the municipality's Public Utilities Commission (PUC). Walkerton's water was drawn from the wells, treated with chlorine and distributed to the residents of Walkerton. Well number five in particular had a history of poor water quality; past tests had shown fluctuations in turbidity as high as 3.5NTU (Hrudey and Hrudey, 2004). Also, chlorine practices did not follow procedure; operators were not regularly measuring chlorine levels and chlorine was maintained at levels lower than required. In May of 2000, the town's water supply became contaminated with *E.coli*

O157:H7 and *Campylobacter jejuni* resulting in the death of seven people and the illness of 2,300 (O'Connor, 2002a).

Assessment of the Water System:

When the Walkerton water system was assessed using the flow diagram in Figure 3.1 the following critical control points (CCPs) were noted:

1. *Ground water is under the direct influence of surface water/ there is a history of contamination-* Walkerton's well five was a shallow well with a casing that extended 5m below the surface (O'Connor, 2002a, 15). Shallow wells are often vulnerable to surface contamination due to surface water rapidly traveling through cracks and fissures in the ground, reaching the well. Well five was identified as being vulnerable to contamination at the time it was first brought into use (Hrudey and Hrudey 2004, 111). Wells should be constructed in a manner that prevents surface water from ponding around the top of the well by locating the well away from areas of depressions; the earth should be mounded around the well so water quickly flows away from it and the well should have a tight fitting lid and a water-tight well casing at least 6m deep (Agriculture and Agri-Food Canada, 2003, 35).

CCP 1- ground water under the direct influence of surface water

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Close the well and use another source of water	2	2	4	8
3. Improve land grading around well/ create a protection zone	3	4	3	10.5

2. *Lack of water treatment/ there is the likelihood for failure-* Omitting water filtration is a common practice with good quality ground water because as water moves through soil towards the aquifer, pathogens are filtered from the water (Spellman, 2003).

Unfortunately, the water at Walkerton was not good quality water, a fact that had been known for many years before the Walkerton outbreak. Walkerton's water was required to be treated with sufficient chlorine to retain a chlorine residual of 0.5mg/L of water after 15 minutes of contact time (O'Connor, 2002a, 155). However this was not being done, instead the operators had failed to maintain chlorine levels and the records were being falsified.

CCP 2- lack of treatment/ likelihood of failure

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Install continuous chlorine monitor	4	4	3	12
3. Put a back-up chlorinator in place	3	4	3	10.5
4. Hire a full time operator to monitor the process	3	2	3	7.5
5. Install a multi-step treatment process	2	2	5	10

3. *There is no trained water operator –* Appropriate water monitoring includes measuring the chlorine residual daily, sampling the raw water and sampling the water in the distribution system monthly for microbiological testing (Hrudey et al, 2002). The Koebel brothers, who were in charge of Walkerton's water system, failed to monitor the water system appropriately (O'Connor, 2002A). They also made false entries on the daily operating sheets, samples were not taken routinely and they were mislabeled or taken

near the treated water location, which would not provide an accurate picture of the waters quality.

CCP 3- no trained water operators

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Ensure water operators are trained and updated regularly	3	3	4	12
3. Have water practices audited regularly	3	3	2	6
4. Have water operators trained and have practices audited	3	3	5	15

4. *Emergency plan does not exist*- An emergency plan should exist for all water systems in case of any unforeseen event, such as a power outage, if the water operator becomes ill, a flood occurs, or even an adverse water result is reported. The water operator should have a designated list of who must be informed when a serious event occurs such as the Health Department or the Ministry of the Environment. The Walkerton PUC failed to notify authorities when an adverse water sample was reported and even passed on false information to health authorities.

CCP 4- emergency plan

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Provide a list of authorities to inform if a adverse event occurs	5	5	5	25

Conclusions:

The assessment of the water system identified four areas of concern. Based on the trade-off tables the following are the most desirable courses of action to take to ensure that the risk to the water system is reduced:

- 1) A zone of protection should be installed surrounding the well to prevent run-off and other contamination from reaching the wellhead.
- 2) A continuous chlorine monitor should be installed on the treatment system that would alert operators if chlorine levels were low or the chlorination equipment was malfunctioning.
- 3) The water operators should be trained and their practices audited regularly to ensure they are maintaining the security of the water system.
- 4) An emergency response list should be created to ensure the correct authorities are informed of adverse events. Such a list is easy to make and will save time during an emergency.

Scenario 2- The North Battleford Waterborne Outbreak

The Water System:

North Battleford's water supply was drawn from the North Saskatchewan River. The water was treated through a traditional treatment process, which included coagulation, gravity clarification, anthracite sand filtration and chlorine disinfection. The inlet pipe for the treatment plant was located 3.5 km downstream of the city's sewage outfall causing the water supply to be heavily polluted. In 1993 water sampling showed that fecal coliforms were as high as 150,000

per 100mL of water, further sampling revealed that the North Saskatchewan River exhibited *Cryptosporidium parvum* as high as any water supply in North America (Hrudey and Hrudey, 2004, 318). The North Battleford treatment plant did have designated water operators; however, the operators lacked the training to appreciate the risks to drinking water and to act in a way that would protect the water supply. From March 20 to April 26, 2001 the town experienced a substantial waterborne outbreak caused by *Cryptosporidium parvum* resulting in the illness of 5,800 to 7,100 people.

Assessment of the water system:

When the North Battleford water system was assessed using the flow diagram in Figure 3.1 the following critical control points (CCPs) were noted:

1. *A foreseeable threat exists to the water source-* the towns' sewage outflow was up-gradient of the treatment plants intake point by only 3.5km. Sewage can contain numerous pathogenic organisms and the outfalls location greatly increases the need for proper water treatment. As early as 1993 it was known that the water source contained *Cryptosporidium parvum*, which can be difficult to remove from the water supply due to its small size and resistance to chlorine disinfection. The fact that these organisms were known to be in the water supply and that they are so hard to remove makes the safety of the water supply a CCP.

CCP 1- a foreseeable threat exists to the water source

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Install water inlet pipe for treatment plant upstream of sewage plant	2	1	4	6
3. Institute stricter effluent standards for sewage	2	3	3	7.5
4. Institute ozone/ UV treatment as a supplement for <i>Cryptosporidium</i> in the water supply	3	4	3	10.5

2. *The treatment process*- although the North Battleford water treatment system was a multi-process system, there was the possibility that high turbidity could render the system unable to cope with the risks. Surface water often has increased turbidity, which increases the difficulty in treating the water (Spellman. 2003). At the time of the outbreak, the treatment units were dealing with waters with turbidity from 2.5 to 21NTU. Without an effective treatment process, a step further along in the system would not be able to control such a risk.

CCP 2- the treatment process

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Institute strict operating parameters for treatment	4	4	4	16
3. Replace treatment unit with new automated unit that will shut down when not operating properly	3	4	4	14
4. Monitor water with regular water samples	4	3	1	3.5

3. *The water operator*- the North Battleford water operators did not have sufficient understanding of the hazards to the water system, water operators must be knowledgeable about monitoring practices and the appropriate responses to adverse results. At North Battleford, the operators lacked the ability to identify the risks to drinking water and to act to protect the water supply. For example, when operators at North Battleford backwashed the filters, water was not run to waste to allow the filters to ripen and provide greater protection; in fact, running water to waste after a backwash was not a common practice at the plant. Producing safe drinking water cannot be accomplished exclusively through improved infrastructure, but requires operators to be knowledgeable and respond appropriately to adverse events (Hrudey et al, 2002, 405).

CCP 3- the water operator

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Ensure water operators are trained and updated regularly	3	3	4	12
3. Have water practices audited regularly	3	3	2	6
4. Have water operators trained and have practices audited	3	3	5	15

Conclusions:

The assessment of the water system identified three areas of concern. Based on the trade-off tables, the following are the most desirable courses of action to take in order to reduce the risk to the water system:

- 1) An ozone or UV treatment device should be installed to reduce the known threat of *Cryptosporidium* in the water. Ozone or UV treatment is considered the best treatment to remove *Cryptosporidium* in the water supply according to the Canadian Council of Ministers of the Environment (2004) [refer to table 3.1].
- 2) Strict operating parameters should be instituted in the treatment process, for example when turbidity of the effluent is above 0.3NTU the water is unsafe to provide to consumers. Hrudey et al. notes that "allowing treated water turbidity levels to exceed 0.3 NTU could allow *Cryptosporidium* into treated water" (2002, 404).
- 3) The water operators should be trained and their practices audited regularly to ensure they are maintaining the security of the water system.

Scenario 3- Small water system servicing a snowmobilers' travel lodge

The Water System:

A snowmobiling lodge in Wyoming U.S. serving travelers throughout the winter season was associated with a waterborne outbreak in January 2001 (Anderson et al., 2003). The resort's water was untreated and supplied by a drilled well. The well was located in sandy porous soil that allowed rapid water percolation. The resort had a septic system on the property, which had the correct clearance distance from the well, but the owner of the lodge had recently remodeled the facility to increase the number of guests he could accommodate without checking the septic tank's capacity. The outbreak resulted in 230 cases of the Norwalk virus.

Assessment of the Water System:

When the travel lodge's water system was assessed using the flow diagram in Figure 3.1, the following critical control points (CCPs) were noted:

1. *Ground water under the direct influence of surface water/ foreseeable threat exists to the water system-* two threats to the water system existed; the first was the septic system on the property. Although it was noted in the report by Anderson et al. (2003) that the required separation distance was met, the possibility for contamination cannot be discounted. Severe system malfunctions can still result in the contamination of the water supply. The second threat to the water system was the porous soil quality, which increased the risk for contamination entering the water supply.

CCP 1- ground water under the direct influence of surface water

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Choose another water source- i.e. re-drill the well	1	2	4	6
3. Monitor the quality of the water with frequent microbial tests	4	3	1	3.5
4. Install simple treatment device to ensure the safety of the water	4	4	3	12
5. Install simple treatment device and conduct frequent microbial tests	3	3	4	12

2. *No water treatment*- the lack of water treatment in a water system that is known to have poor hydrological conditions leaves the water supply vulnerable to contamination. A simple chlorination unit can provide protection from *E.coli* and *Giardia*; however, if the water source faces contamination by *Cryptosporidium*, other treatment methods are available (Canadian Councils of Ministers of the Environment, 2004, 128).

CCP 2- no water treatment

Alternatives	Decision making criteria			
	Cost	Feasibility	Efficacy	Score
1. Do nothing	5	5	1	5
2. Install multi-process water treatment	1	1	5	5
3. Install simple treatment device	4	4	3	12
4. Install simple treatment device and monitor water with microbial testing	3	3	4	12

3. *No trained water operator*- in small drinking water systems, often the owner and operator are the same person and they have had little if any water training. It is critical that these operators attend formal water training in order to be able to identify possible threats to the water system. Had the operator of the travel lodge had basic water operator training, one would hope that he would have been more conscious of the risk in increasing the septic tank load and its effect on the water source.

CCP 3- no trained water operator

Alternatives	Decision making criteria			Score
	Cost	Feasibility	Efficacy	
1. Do nothing	5	5	1	5
2. Ensure water operator/ owner is trained and updated regularly	3	2	4	10
3. Have water practices audited regularly	3	3	2	6
4. Have water operator trained and have practices audited	3	2	5	12.5

Conclusions:

The assessment of the water system identified three areas of concern. Based on the trade-off tables, the following are the most desirable courses of action to take for the water operator to ensure that they reduce the risk to the water system:

- 1) A simple treatment device should be installed and water quality should be monitored through frequent microbial testing. This alternative received the same score as simply installing a treatment device with a score of 12 in two cases- ground water under the influence of surface water and no treatment device for the system. However, installing the treatment device and conducting testing scored higher in regard to efficacy at 4 versus

3. A simple chlorinator can provide protection from many contaminants but frequent water testing will ensure continued success of the treatment device.
- 2) The water operator/owner should be trained and their practices audited regularly to ensure they are maintaining the security of the water system. This protection measure would have identified changes to the water system or surrounding activities like an increase in sewage load and a possible risk to the water supply.

Chapter Five: Conclusions and Recommendations

5.1 Concluding Remarks

An examination of management approaches for water systems across Ontario has identified that only one management system has been adopted in Ontario, the DWQMS. This sole attempt at managing water systems only applies to large, municipally-run water systems and is not appropriate to small drinking water systems. Research has identified that there is a need for a risk assessment/risk management approach for small drinking water systems; nonetheless no such system has yet been developed in Ontario. This study has attempted to identify the gaps in research and move the discussion forward by proposing a risk assessment and risk management approach that could be adopted for use by public health professionals and the owners and operators of small water systems.

The qualitative analysis conducted on past waterborne outbreaks to assess the causes of system failures determined that the water system can be broken into five components: the water source, treatment, operator and emergency response, the distribution system and water storage. At each of these junctures, critical control points can be identified and control measures put in place to reduce the risk of contamination entering the water supply. This provides multiple opportunities to institute protection measures that will protect the water supply.

This study has been based on qualitative data to identify hazardous practices in the water system. In order to accurately identify the quantitative significance of failure probabilities in a water system, a detailed assessment of past outbreaks must be carried out. While there is ample data on waterborne outbreaks dating back to the 1970s there has been insufficient research conducted on multiple factors interacting to contribute to an outbreak. A better understanding of

these failures is critical if the threats to the water system are to be fully understood and controlled based on the level of risk they pose.

In order to manage identified threats to a water source, a risk management framework has been created to assist the user in identifying all options for reducing the risk and ranking these options. Identifying CCPs in the water system is only the first step in reducing the risk to the public's health, and further action is required to manage such threats. The water source must be managed appropriately to ensure protection measures are instituted. Regulators and owner/operators must work together to identify CCPs, identify options and institute protection measures. In many cases a protection measure instituted at one CCP may eliminate CCPs identified further down stream resulting in a more secure water supply with less work. This was demonstrated in chapter four, scenario three, where both CCP one and two identified the same solution.

A qualitative approach to managing risk has been proposed in this study; however, a realistic understanding of the limitations of this tool is necessary. This approach has been created for use by public health professionals, but requires a critical review of the discussed risk assessment and risk management techniques to assess its validity before it could be used to accurately assess the risk of a water system.

5.2 Recommendations

The recommendations given the findings of this study include:

- That identification of risks to water systems be based on the probability that a hazard will cause harm, rather than treating all hazards equally.

- That improvement in the categories, consistency, and precision of waterborne disease outbreak data be made in order to fully understand the causes and prevention measures for risk management decisions.
- That a knowledgeable public health professional be employed to identify true risks to the water system and that they work with small water operators to identify the best protection measures for each individual system.
- That risk assessment and risk management must be employed in tandem to ensure the public's health is protected. Risk assessment alone will not result in a secure water system.

Overall, greater research is needed into the creation of risk assessment and risk management tools that can be used in real life situations to analyze and prevent waterborne outbreaks.

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Appendices

Appendix 2.1: The Principles of Water Filtration

Binnie et al (2002, 139) describes five filter mechanisms that remove particles from the water supply:

Interception- is when the filter media intercepts a particle moving uniformly. This factor is influenced by the diameter of the particle and the diameter of the filter media. The larger the particle or the smaller the filter media is the greater the possibility that the particle will collide with the media and be removed. Simply reducing the size of the filter media can increase the efficiency of filtration.

Sedimentation- gravitational forces act on, and influence, particles during filtration. Dense particles and large particles are removed much more efficiently due to this principle.

Diffusion- particles in water move randomly and can be 'pushed' by other particles or forces. As these particles move through filtration they will randomly collide with the filter media and be removed from the water stream. As water temperatures increase particle movement increases, which increases the rate of particle removal by diffusion.

Hydrodynamic action- as a particle moves close to a piece of filter media the velocity gradient in the water creates pressure differences across the particle, which moves the particle towards the filter media. The influence of hydrodynamic action in filtration is believed to be very small.

Inertia- the inertia of a particle about to collide with a grain of filter media will cause a collision, unless other forces, such as hydrodynamic forces divert it. Binnie et al (2002) does not consider inertia a significant factor in filtration.

Appendix 2.2
Compilation of Waterborne Outbreaks from 1974-2004
Various Sources

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	system failure					Water Source	Country	Notes
										Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures		
1	Shigella	Grudey, S. and E. Grudey (2004)	10		1200	1974	Jan-March	Large	Chlorination				x	x		US Florida	Chlorination deficiencies, poor monitoring and sewage discharging near the well
2	Giardia lamblia	Grudey, S. and E. Grudey (2004)	350		5300	1974	Nov-June	Large	Chlorinated						x	US New York	Due to the lack of filtration and reliance on low chloramination in cold water
3	E.coli	Grudey, S. and E. Grudey (2004)	20		2200	1975	June-july	Small	chlorinated				x			US Oregon	National park, sewage flowed to water supply, no chlorine levels monitored
4	Giardia lamblia	Grudey, S. and E. Grudey (2004)	25		600	1976	April-May	Large	chlorinated						x	US Washington	Chlorinator was broken for a few days resulting in manual chlorination and poor contact time
5	Giardia lamblia	Grudey, S. and E. Grudey (2004)	213		6900	1977	March-May	Large	filter/chlorinated				x			US New Hampshire	Leaking sewage systems and failures in chlorination and filter technology could have lead to outbreak.
6	Campylobacter jejuni	Grudey, S. and E. Grudey (2004)	15		3000	1978	May-June	Large	chlorinated	x			x	x		US Vermont	Chlorination had no residual, heavy rain fall leading up to the outbreak and previous bad water results indicating a poor source- UNSURE OF CAUSE
7	Giardia lamblia	Grudey, S. and E. Grudey (2004)	407		2900	1979	July-Dec	Large	Chlorination	x					x	US Pennsylvania	Chlorinator failure and heavy rains attributed to the outbreak, failure to filter water
8	Norwalk	Grudey, S. and E. Grudey (2004)			1500	1980	Aug	Large	chlorinated		x					US Georgia	Cross connections and backflow to a plants with poor water
9	Hep A	Grudey, S. and E. Grudey (2004)	36		7900	1980	June	Large	chlorine sedimentation/chlorination	x			x			US Texas	Unknown cause but preceded heavy rains and had numerous sewage systems nearby
10	Giardia lamblia	Grudey, S. and E. Grudey (2004)	24		780	1980	June-Aug	Large		x					x	US Montana	High volume run off and inadequate chlorine residual did not use chemical
11	Rotavirus	Grudey, S. and E. Grudey (2004)			80	1981	March	Large	filter/chlorinated						x	US Colorado	coagulation, chlorinator broke and sewage treatment plant was upstream with high bacterial levels
12	unknown/gastro	MMWR Vol55 SS-12			16	1982	May	small	Unspecified						x	US New York	Restaurant
13	Norwalk	Grudey, S. and E. Grudey (2004)	895	2	3000	1983	Feb	Large	sedimentation/filtration/chlorination				x	x		CA Alberta	Sewage spill and inability to achieve coagulation

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
14	unknown/gastro	MMWR vol39 No.SS-1			113	1983	June	small	none						x		SW	US New Mexico	Camp
15	Campylobacter jejuni	Brudey, S. and E. Brudey (2004)	11		865	1983	May	Large	sedimentation/filtration/chlorination			x				x	GW	US Florida	chlorination deficiencies and contamination into the coagulation unit by bird droppings
16	Cryptosporidiosis/ Norwalk	Brudey, S. and E. Brudey (2004)/Solo-Gabriele, H and S. Neumeister (1996)	47/4		202	1984	May-June	Large	chlorination				x				GW	US Texas	dye test revealed towns sewage was leaking into the well
17	Campylobacter jejuni	Brudey, S. and E. Brudey (2004)	57		241	1985	April	Large	none	x		x		x			GW	CA Ontario, orar	water was not treated and monitored only once per week
18	Campylobacter	MMWR Vol37 SS-2	19			1985	April	small	None						x		GW	US Arkansas	Resort
19	Giardia lamblia	MMWR Vol37 SS-2	32			1985	April	Small	None						x		SW	US Virginia	Resort
20	unknown/gastro	MMWR Vol37 SS-2			19	1985	Aug	small	unspecified							x	GW	US New York	Recreation centre
21	Shigella	MMWR Vol37 SS-2			27	1985	Aug	small	None						x		GW	US Pennsylvania	Camp
22	unknown/gastro	MMWR Vol37 SS-2			274	1985	Aug	Large	unspecified							x	GW	US Puerto Rico	community water supply
23	unknown/gastro	MMWR Vol37 SS-2			21	1985	Aug	Large	Unspecified							x	GW	US Vermont	Trailer Park
25	unknown/gastro	MMWR Vol37 SS-2			18	1985	July	small	None						x		GW	US Illinois	Recreation centre
26	unknown/gastro	MMWR vol39 No.SS-1			4	1985	June	small	none						x		GW	US New York	Restaurant
28	campylobacter	MMWR vol39 No.SS-1			24	1985	March	small	none						x		SW	US Arkansas	Camp
29	unknown/gastro	MMWR vol39 No.SS-1			70	1985	May	small	Unspecified							x	GW	US Pennsylvania	Restaurant
30	unknown/gastro	MMWR vol39 No.SS-1			11	1985	Nov	small	Unspecified							x	GW	US Pennsylvania	Restaurant
31	unknown/gastro	MMWR Vol37 SS-2			105	1985	Nov	small	none						x		SW	US Vermont	School
32	unknown/gastro	MMWR Vol37 SS-2			19	1985	Nov	small	none						x		SW	US Vermont	School
33	Giardia lamblia	Brudey, S. and E. Brudey (2004)/MMWR vol 37	703		3800	1985	Nov-Jan	Large	Chlorination								SW	US Massachusetts	chorine was being passed to waste, no filtration
34	unknown/gastro	MMWR vol39 No.SS-1			275	1985	Sept	small	none						x		GW	US Pennsylvania	School
35	unknown/gastro	MMWR Vol37 SS-2			59	1985	Sept	Small	None						x		GW	US Oklahoma	camp

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
37	Giardia lamblia	MMWR vol39 No.SS-1			23	1986	Aug	small	Unspecified							x	GW	US Colorado	Resort
38	Salmonellosis	MMWR vol39 No.SS-1			9	1986	Aug	Large	none						x		GW	US Mississippi	Community water supply
39	Norwalk	MMWR vol39 No.SS-1			135	1986	Aug	small	Unspecified							x	GW	US South Dakota	Camp
40	unknown/gastro	MMWR vol39 No.SS-1			45	1986	Feb-Mar	small	Unspecified							x	GW	US Vermont	Motel
41	Giardia lamblia	MMWR vol39 No.SS-1			68	1986	Jan	Large	Unspecified							x	SW	US Vermont	Trailer park, River
42	Shigella	MMWR vol39 No.SS-1			25	1986	July	Large	none						x		GW	US Alabama	Trailer park
43	unknown/gastro	MMWR vol39 No.SS-1			110	1986	July	small	Unspecified							x	GW	US Virginia	Camp
45	unknown/gastro	MMWR vol39 No.SS-1			36	1986	Jun	small	Unspecified							x	SW	US New Mexico	Resort- river water
46	unknown/gastro	MMWR vol39 No.SS-1			90	1986	June	small	none						x		GW	US Colorado	camp
47	unknown/gastro	MMWR vol39 No.SS-1			233	1986	June	small	Unspecified							x	GW	US New Mexico	Camp
48	Salmonellosis	MMWR vol39 No.SS-1			61	1986	June	Large	Unspecified		x						GW	US Utah	Community water supply
49	Giardia lamblia	Brudey, S. and E. Brudey (2004)	362		3100	1986	June- Nov	Large	Chlorination	x						x	SW	CA BC Penticton	Lack of filtration and spring run off causing turbidity
50	Campylobacter	MMWR vol39 No.SS-1			250	1986	May	Large	Unspecified		x						SW	US Oklahoma	Community water supply
51	Giardia lamblia	MMWR vol39 No.SS-1			12	1986	Nov	Large	Unspecified							x	SW	US Maine	Community water supply
52	Giardia lamblia	MMWR vol39 No.SS-1			44	1986	Nov	Large	Unspecified							x	SW	US New York	Community water supply
53	unknown/gastro	MMWR vol39 No.SS-1			213	1986	Sept	small	Unspecified							x	GW	US Pennsylvania	Restaurant
54	Giardia lamblia	MMWR vol39 No.SS-1			513	1987	April	large	Unspecified							x	SW	US Pennsylvania	Community water supply
55	unknown/gastro	MMWR vol39 No.SS-1			22	1987	Aug	small	none						x		GW	US Pennsylvania	camp
		Brudey, S. and E. Brudey (2004)/MMWR vol39							sedimentation/filtration/chlorine										poor flocculation and not running filters to waste after backwashing; sewage line blockage
56	Cryptosporidiosis		58		13000	1987	Jan	Large	lorine	x			x	x			SW	US Georgia	
57	Giardia lamblia	MMWR vol39 No.SS-1			120	1987	July	Large	Unspecified		x						GW	US Connecticut	Community water supply

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	system failure				Failure to institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
58	unknown/gastro	MMWR vol39 No.SS-1			72	1987	July	small	none						x		GW	US Illinois	Restaurant
59	unknown/gastro	MMWR vol39 No.SS-1			71	1987	July	small	none						x		SW	US New Hampsh	Camp
60	unknown/gastro	MMWR vol39 No.SS-1			1400	1987	July	Large	Unspecified							x	SW	US Puerto Rico	Community water supply
61	unknown/gastro	MMWR vol39 No.SS-1			21	1987	July	Large	none						x		GW	US Vermont	Trailer park community
62	Shigella	MMWR vol39 No.SS-1			1800	1987	Oct	Large	Unspecified							x	SW	US Puerto Rico	Community water supply
63	unknown/gastro	MMWR vol39 No.SS-1			9	1987	Sept	small	none						x		GW	US Maine	Resort
64	unknown/gastro	MMWR vol39 No.SS-1			30	1988	Aug	small	none						x		GW	US Missouri	Golf Course
65	Giardia lamblia	MMWR vol39 No.SS-1			90	1988	Feb	Large	Unspecified							x	SW	US Colorado	Resort
66	unknown/gastro	MMWR vol39 No.SS-1			80	1988	July	small	Unspecified							x	GW	US Colorado	Resort
67	Giardia lamblia	MMWR vol39 No.SS-1			172	1988	July	Large	Unspecified							x	SW	US Pennsylvania	Community water supply
68	unknown/gastro	MMWR vol39 No.SS-1			42	1988	July	small	Unspecified							x	GW	US South Dakota	Hotel
69	Norwalk	MMWR vol39 No.SS-1			339	1988	June	small	none						x		GW	US Idaho	Camp
70	Shigella	MMWR vol39 No.SS-1			900	1988	May	small	Unspecified							x	GW	US Texas	Restaurant
71	unknown/gastro	MMWR vol39 No.SS-1			340	1988	May	small	none						x		GW	US Wisconsin	Restaurant
72	unknown/gastro	MMWR vol39 No.SS-1			7	1988	Nov	Large	none						x		SW	US Colorado	Community water supply
73	unknown/gastro	MMWR vol39 No.SS-1			7	1988	Nov	small	none						x		GW	US Maine	Restaurant
74	unknown/gastro	MMWR vol39 No.SS-1			26	1988	Sept	small	none						x		GW	US Pennsylvania	camp
75	unknown/gastro	MMWR vol40 NoSS-3			54	1989	April	small	Unspecified							x	GW	US Maine	Restaurant
76	Giardia Lamblia	MMWR vol40 NoSS-3	308			1989	April	Large	Unspecified							x	SW	US New York	Community water supply
77	suspect Norwalk	MMWR vol40 NoSS-3	3		900	1989	April	seasonal	none				x				GW	US Arizona	sewage rapidly entered ground water source- resort

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	system failure					Water Source	Country	Notes
										Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures	Treatment Deficiencies	
		Brudey, S. and E. Hruday (2004)MMWR vol40															
78	E.coli 0157:H7	MMWR vol40 NoSS	21	4	243	1989	Dec-Jan	Large	None		x	x	x		x		Sewage overflow during a water main break
79	Giardia lamblia	MMWR vol40 NoSS	19			1989	Feb	Large	Unspecified								Community water supply
80	Giardia Lamblia	MMWR vol40 NoSS	53			1989	July	Large	Unspecified								Community water supply
81	unknown/gastro	MMWR vol40 NoSS			50	1989	July	small	None						x		Community water supply
82	Giardia Lamblia	MMWR vol40 NoSS	152			1989	June	Small	Unspecified								Reservoir for prison
83	unknown/gastro	MMWR vol40 NoSS			22	1989	June	Large	None						x		Housing development
84	unknown/gastro	MMWR vol40 NoSS			700	1989	Sept	Large	none						x		Community water supply
85	Giardia lamblia	MMWR vol40 NoSS	123			1990	Aug	Large	Unspecified							x	Community water supply
86	unknown/gastro	MMWR vol40 NoSS			150	1990	Aug	small	Unspecified		x						Resort
87	unknown/gastro	MMWR vol40 NoSS			12	1990	Feb	small	Unspecified								camp
88	unknown/gastro	MMWR vol40 NoSS			76	1990	Feb	small	none						x		Resort
89	Giardia lamblia	Brudey, S. and E. Hruday (2004)	124			1990	Jan-April	Large	None			x			x		untreated surface water was prone to contamination by beavers
90	unknown/gastro	MMWR vol40 NoSS			52	1990	July	small	Unspecified								Resort
91	Giardia lamblia	MMWR vol40 NoSS	18			1990	March	small	none						x		Lodge
92	Giardia lamblia	MMWR vol40 NoSS	24			1990	March	small	Unspecified							x	Resort
93	unknown/gastro	MMWR vol40 NoSS			109	1990	May	Large	Unspecified							x	Community water supply
94	unknown/gastro	MMWR vol40 NoSS			1000	1990	May	small	Unspecified							x	Country Club
95	Hep A	MMWR vol40 NoSS			3	1990	Nov	Large	Unspecified							x	community well
96	unknown/gastro	Moore et al. (1994)			33	1991	Aug	small	None						x		Resort
97	unknown/gastro	Moore et al. (1994)			17	1991	Aug	small	none						x		Restaurant
98	unknown/gastro	Moore et al. (1994)			38	1991	Aug	small	none						x		camp

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
99	Cryptosporidium	Moore et al. (1994)	551			1991	Aug	small	unspecified			x				x	GW	US Pennsylvania	Picnic grounds; well influenced by surface water
100	unknown/gastro	Moore et al. (1994)			202	1991	Aug	Large	unspecified		x						SW	US Puerto Rico	Correction facility
101	unknown/gastro	Moore et al. (1994)			9847	1991	Aug	Large	unspecified							x	SW	US Puerto Rico	Community water supply
102	Giardia lamblia	Moore et al. (1994)	15			1991	July	small	Unspecified		x						SW	US California	Recreation centre
103	unknown/gastro	Moore et al. (1994)			30	1991	July	small	Unspecified		x						GW	US Minnesota	Resort
104	unknown/gastro	Moore et al. (1994)			8	1991	July	small	unspecified							x	GW	US Pennsylvania	Restaurant
105	unknown/gastro	Moore et al. (1994)			1320	1991	June	small	None						x		GW	US Michigan	Campground
106	unknown/gastro	Moore et al. (1994)			30	1991	June	small	None						x		GW	US Minnesota	Campground
107	unknown/gastro	Moore et al. (1994)			170	1991	June	small	unspecified							x	GW	US Pennsylvania	Picnic grounds
108	unknown/gastro	Moore et al. (1994)			300	1991	June	small	unspecified							x	GW	US Pennsylvania	camp
109	Giardia lamblia	Moore et al. (1994)			13	1991	Sept	small	unspecified							x	GW	US Pennsylvania	Park
110	Hep A	Kramer et al. (1996)/MMWR vol45			46	1992	Apr	small	None						x		GW	US Missouri	School
111	unknown/gastro	Moore et al. (1994)			107	1992	April	small	unspecified		x						GW	US New York	Restaurant
112	unknown/gastro	Moore et al. (1994)			80	1992	Aug	small	Unspecified							x	GW	US Pennsylvania	camp
113	unknown/gastro	Moore et al. (1994)			250	1992	Feb	small	unspecified							x	SW	US Minnesota	Restaurant
114	unknown/gastro	Moore et al. (1994)			200	1992	Jan	small	none						x		GW	US North Carolina	Restaurant
115	Cryptosporidiosis	Brudey, S. and E. Hudey (2004)/Solo-Gabriele, H and S. Neumeister (1996)	100		15000	1992	Jan-June	Large	sedimentation/filtration/chlorination			x					SW	US Oregon	sewage discharges (source contamination) upstream of water inlet combined with poor settling during treatment
116	Shigella	Kramer et al. (1996)/MMWR vol45	11			1992	July	small	Unspecified		x						GW	US Missouri	camp ground
117	Shigella	Moore et al. (1994)	150			1992	July	small	none						x		GW	US Wyoming	Park ground

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
118	unknown/gastro	Moore et al. (1994)			129	1992	June	small	unspecified		x						GW	US Ohio	Campground
119	unknown/gastro	Moore et al. (1994)			42	1992	June	small	Unspecified							x	GW	US Pennsylvania	camp
120	Giardia lamblia	Moore et al. (1994)			15	1992	March	Large	none						x		GW	US Idaho	Trailer park- year round
121	Giardia lamblia	Moore et al. (1994)	80			1992	March	Large	unspecified							x	SW	US Nevada	Community water supply
122	unknown/gastro	Moore et al. (1994)			5	1992	March	small	Unspecified							x	GW	US Pennsylvania	Restaurant
123	unknown/gastro	Kramer et al. (1996)/MMWR vol45			50	1992	May	small	Unspecified							x	GW	US Pennsylvania	camp
124	unknown/gastro	Moore et al. (1994)			50	1992	May	small	Unspecified							x	GW	US Pennsylvania	camp
125	unknown/gastro	Moore et al. (1994)			57	1992	May	small	Unspecified							x	GW	US Pennsylvania	camp
126	Cryptosporidium	Solo-Gabriele, H and S. Neumeister (1996)	5		27	1993	Aug	small	Unspecified		x		x				SW	US Minnesota	backflow of sewage into distribution system; Resort
127	Giardia lamblia	Kramer et al. (1996)/MMWR vol45			20	1993	Jan	Large	filtered							x	GW	US Pennsylvania	Trailer park
128	unknown/gastro	Kramer et al. (1996)/MMWR vol45			65	1993	Mar	small	none						x		GW	US Pennsylvania	Ski Resort
129	Cryptosporidium	Craun et al. (1998)	193		23000	1993	March	Large	Ozonation	x						x	GW	CA ON Waterloo	Well under influence of runoff after heavy rains; ozone applied but not high enough to be a disinfectant
130	Cryptosporidiosis	Hrudey, S. and E. Hrudey (2004)/Kramer et al. (1996)	285	50	4E+05	1993	March-April	Large	sedimentation/filtration/chlorination			x				x	SW	US Milwaukee	High turbidities and sewage outflow to river increased risk of contamination; Water contaminated by a contaminated water storage tower
131	campylobacter	Kramer et al. (1996)/MMWR vol45	32			1993	Nov	small	Unspecified		x						GW	US Minnesota	Birds accessed water storage and droppings caused contamination, no treatment and flushing the lines of an old system resulted in contamination
132	Salmonellosis	Hrudey, S. and E. Hrudey (2004)/Angulo, F. et al. (1997)	31	7	650	1993	Nov-Dec	Large	None		x	x			x		GW	US Missouri	

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
133	Giardia lamblia	Kramer et al. (1996)/MMWR vol45			7	1993	Sept	Large	none						x		GW	US South Dakota	untreated ground water
134	unknown/gastro	Kramer et al. (1996)/MMWR vol45			40	1993	Sept	small	none						x		GW	US South Dakota	Resort no water treatment
135	unknown/gastro	Kramer et al. (1996)/MMWR vol45			72	1994	Aug	small	None						x		GW	US Maine	camp
136	Cryptosporidium	Kramer et al. (1996)/MMWR vol45	15		86	1994	Aug	Large	none				x		x		GW	US Washington	Evidence of treated waste water contamination
137	Giardia lamblia	Grudey, S. and E. Grudey (2004)	26		160-330	1994	Feb-May	Large	coagulation/filtration/chlorination	x			x			x	SW	CA ON Temagami	Sewage release upstream, heavy melt and no chlorine contact time
138	Cryptosporidium	Solo-Gabriele, H and S. Neumeister. (1996)	78			1994	Jan-April	Large	Chlorination/sedimentation/n/ filtration			x				x	SW	US Nevada	Sewage from boats dumped into water source, possible failure of the treatment system
139	Campylobacter	Kramer et al. (1996)/MMWR vol45	19			1994	June	small	None						x		GW	US Minnesota	park
140	Shigella	Kramer et al. (1996)/MMWR vol45			230	1994	June	small	None						x		GW	US New York	camp
142	unknown/gastro	Kramer et al. (1996)/MMWR vol45			118	1994	Mar	small	None						x		GW	US Indiana	restaurant
143	Giardia lamblia	Kramer et al. (1996)/MMWR vol45	304			1994	Mar	Large	Unspecified		x				x		SW	US Tennessee	Unchlorinated spring water used as well as distribution system deficiencies at a correctional facility
144	Giardia Lamblia	Kramer et al. (1996)/MMWR vol45			18	1994	May	Large	unfiltered but chlorinated							x	SW	US New Hampshire	Unfiltered reservoir water
145	Giardia Lamblia	Kramer et al. (1996)/MMWR vol45			36	1994	May	Large	unfiltered but chlorinated							x	SW	US New Hampshire	Lake water un filtered weak treatment methods, spiked rain fall and cat and cougar feces around reservoir contaminated it.
146	Toxoplasma gondii	Grudey, S. and E. Grudey (2004)	100		2900-770	1994	Oct-May	Large	chlorination	x						x	SW	CA BC Victoria	
147	unknown/gastro	Kramer et al. (1996)/MMWR vol45			200	1994	Sept	small	Unspecified							x	GW	US Pennsylvania	Resort

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	system failure					Water Source	Country	Notes	
										Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies				Failure to institute protection measures
148	Shigella	MMWR vol 47 ss-5	83			1995	Aug	small	none					x	GW	US Idaho	resort	
149	unknown/gastro	MMWR vol 47 ss-5			450	1995	Aug	small	none					x	GW	US Montana	camp ground	
150	unknown/gastro	MMWR vol 47 ss-5			19	1995	Aug	small	none					x	GW	US Pennsylvania	untreated well water at an inn	
151	unknown/gastro	MMWR vol 47 ss-5			26	1995	Aug	small	unspecified						x	GW	US Wisconsin	treatment deficiency at restaurant well
152	unknown/gastro	MMWR Vol 55 SS-12			30	1995	Aug	small	None				x		GW	US New York	Motel	
153	Giardia lamblia	MMWR vol 47 ss-5	1449			1995	Dec	Large	unspecified						SW	US New York	failure at the water utility	
154	E.coli 0157:H7	MMWR vol 47 ss-5	33			1995	July	small	Unspecified						SW	US Minnesota	camp	
155	Giardia lamblia	MMWR vol 51 SS-8			87	1995	July	Large	Unspecified		x				GW	US Washington	community water supply	
157	unknown/gastro	MMWR vol 47 ss-5			48	1995	June	small	none					x	GW	US South Dakota	Untreated well water at camp	
158	SRSV	Brudey, S. and E. Brudey (2004)	8		433	1995	june-july	small	none			x		x	GW	CA Yukon	Motel septic system leaked into well ill travellers, dye test conducted	
160	Shigella	MMWR vol 47 ss-5	10			1995	Oct	small	Unspecified						GW	US Oklahoma	treatment deficiency at a store well	
161	unknown/gastro	MMWR vol 47 ss-5			18	1995	Sept	Large	unspecified						GW	US Idaho	Community water supply	
162	unknown/viral	MMWR vol 47 ss-5			148	1995	Sept	Large	Unspecified		x				SW	US Wisconsin	distribution problem affecting a school	
163	unknown/gastro	MMWR Vol 55 SS-12			58	1996	Aug	small	None					x	GW	US New York	Camp	
164	Cryptosporidium	Craun et al. (1998)	39		150	1996	Feb	Large	disinfection	x					SW	CA ON Collingwood	Unfiltered water; outbreak followed 100yr storm	
165	unknown/gastro	MMWR vol 47 ss-5			94	1996	July	small	Unspecified						GW	US Idaho	Camp	
166	Plesiomonas Shigelloides	MMWR vol 47 ss-5	60			1996	June	small	unspecified						SW	US New York	Restaurant	
167	unknown/gastro	MMWR vol 47 ss-5			21	1996	June	small	Unspecified		x				GW	US Wisconsin	Restaurant	
168	Cryptosporidiosis	Brudey, S. and E. Brudey (2004)/Craun et al. (1998)	29		2000	1996	May-June	Large	chlorination	x		x			SW	CA BC cranbrook	Cattle grazing close to water reservoir, melting and no filtration	
169	Cryptosporidium	Craun et al. (1998)	100		4000	1996		Large	none			x			SW	CA BC Kelowna	Cattle nearby the water source	

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	system failure				Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
170	Norwalk	MMWR vol51 SS-8			1450	1997	Dec	Small	Unspecified											x	GW	US New York	Ski Resort
171	unknown/gastro	MMWR vol49 No.SS-4			9	1997	July	small	unspecified											x	Sw	US Colorado	cabins
172	unknown/gastro	MMWR vol49 No.SS-4			123	1997	July	small	Unspecified												GW	US New Mexico	Country Club
173	Giardia lamblia	MMWR vol49 No.SS-4	50			1997	June	Large	Unspecified											x	SW	US New York	Community water supply
174	Giardia lamblia	MMWR vol49 No.SS-4			100	1997	June	small	Unspecified												GW	US Oregon	Campground
175	unknown/gastro	MMWR vol49 No.SS-4			16	1997	May	small	Unspecified												GW	US South Dakota	Campground
176	E.coli 0157:H7	MMWR vol49 No.SS-4			4	1997	Sept	small	Unspecified											x	GW	US Washington	Trailer park
177	Shigella	MMWR vol49 No.SS-4	83			1998	Aug	large	Unspecified												GW	US Minnesota	Fairgrounds
178	Cryptosporidiosis	Brudey, S. and E. Brudey (2004)	89		1300-150	1998	July	Large	chlorination								x				GW	US Texas	massive sewage spill into creek which contaminated the wells
179	E.coli 0157:H7	Brudey, S. and E. Brudey (2004)	71		157	1998	June-july	Large	None														ponding water above water collection pipes and wildlife feces also present and no treatment, small tourist town
180	Giardia lamblia	MMWR vol49 No.SS-4			7	1998	May	Large	none												GW	US Wyoming	Community water supply
181	unknown/gastro	MMWR vol49 No.SS-4			10	1998	Oct	Large	Unspecified												SW	US Ohio	Distribution problem at the treatment plant
182	unknown/gastro	MMWR vol51 SS-8			68	1999	Aug	small	none												GW	US Washington	Soccer Match
183	unknown/gastro	MMWR vol51 SS-8			4	1999	Jan	Large	none												GW	US Florida	community water supply
184	unknown/gastro	MMWR vol51 SS-8			31	1999	July	small	none												GW	US California	Camp
185	SRSV	MMWR vol51 SS-8	70			1999	July	Small	Unspecified												SW	US New Mexico	Camp; water system was located on low ground with septic systems surrounding
186	s. typhi	MMWR vol51 SS-8			124	1999	June	Large	clorination												GW	US Missouri	Community water supply; inadequate chlorine

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	system failure					Water Source	Country	Notes	
										Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies				Failure to institute protection measures
187	unknown/gastro	MMWR vol51 SS-8			6	1999	Mar	Large	chlorination & Filtration		x		x			SW	US Florida	community water supply; cross connection with irrigation well and too close to a septic system
188	unknown/gastro	MMWR vol51 SS-8			3	1999	Mar	Large	Chlorination		x					GW	US Florida	Community water supply; cross connection with irrigation well
189	E.coli 0157:H7	MMWR vol51 SS-8	22			1999	Nov	Large	Chlorination						x	GW	US Texas	Community water supply; inadequate chlorine
190	Campylobacter/ E.coli 0157:H7	Crudey, S. and E. Crudey (2004)	45/127	2	2800-5000	1999	Sept	Local Ev	None	x			x			GW	US New York	Washington County Fair Wells were shallow, too close to septic tanks which leaked and untreated water
191	unknown/gastro	MMWR vol51 SS-8			21	2000	April	large	Unspecified						x	GW	US Florida	Trailer Park
192	Giardia lamblia	MMWR vol51 SS-8			27	2000	Aug	small	Filtration and chlorination						x	SW	US Colorado	Resort; failures in filtration system resulted in untreated water
193	E.coli 0157:H7	MMWR vol51 SS-8	29			2000	Aug	Large	Unspecified		x					SW	US Ohio	Faigrounds; back siphonage from the animal show barns
194	Cryptosporidium	MMWR Vol53 SS-8			5	2000	Dec	Large	Unspecified		x					GW	US Florida	Community water supply
195	Norwalk	MMWR vol51 SS-8	147			2000	July	small	none					x		GW	US California	campground
196	unknown/gastro	MMWR vol51 SS-8			65	2000	July	small	none					x		GW	US Idaho	Restaurant
197	Campylobacter	MMWR vol51 SS-8			15	2000	June	small	none		x				x	SW	US Idaho	Camp;no treatment and piping to buildings contained multiple holes allowing contamination to enter
198	Giardia lamblia	MMWR vol51 SS-8			12	2000	June	small	none		x					GW	US Minnesota	Camp; distribution line was connected to sewage line resulting in raw sewage feeding into drinking water
199	Norwalk	MMWR vol51 SS-8			123	2000	June	small	Unspecified							GW	US West Virginia	Camp;well contaminated by sewage from a nearby lagoon

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	system failure					Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
200	Norwalk	MMWR Vol53 SS-8	86			2000	June	small	none											x		GW	US Kansas	Contaminated water at a reception hall holding two events over 2 days
201	unknown/gastro	MMWR vol51 SS-8			19	2000	March	large	Unspecified											x		GW	US Florida	Trailer Park
202	Campylobacter/ E.coli 0157:H7	Hudey, S. and E. Hudey (2004)	105/163	7	2300	2000	May	Large	Chlorination	x						x					x	GW	CA ON Walkert	Heavy rains washed manure to head of well, chlorine levels were low and operators lied to official about waters safety
203	Giardia lamblia	MMWR Vol53 SS-8			6	2001	Feb	Large	Unspecified											x		SW	US Colorado	Community water supply
204	Norwalk	MMWR Vol53 SS-8	230			2001	Jan	small	none									x				GW	US Wyoming	Lodge with snowmobilers; septic tank was over worked and leaked to wells
205	Campylobacter	MMWR Vol53 SS-8	12			2001	June	small	none							x						GW	US Alaska	Bunkhouse; water became contaminated with surface water
206	unknown/gastro	MMWR Vol53 SS-8			19	2001	June	small	clorination											x		GW	US Pennsylvania	Church well, when tested had low chlorine residual
207	Cryptosporidiosis	Hudey, S. and E. Hudey (2004)	375		5800-710	2001	March-April	Large	sedimentation/filtration/chlorination							x				x		SW	CA SASK N Batt	sewage treatment upstream, high turbidities and a system that could not achieve settling
208	Norwalk	MMWR Vol53 SS-8	83			2001	Sept	small	clorination									x				GW	US Wyoming	Restaurant; chlorinator was not working and the septic tank was leaking and leached into the well
209	Giardia lamblia	MMWR Vol53 SS-8			6	2002	April	Large	Unspecified							x						GW	US New York	Trailer Park; contaminated water entered through a cross connection
210	campylobacter/ giardia	MMWR Vol55 SS-12	4		23	2002	Dec	Large	None									x				GW	US New York	Apartment building; sewer line broke flooding the head of the well
211	Norwalk	MMWR Vol53 SS-8			201	2002	July	small	none											x		GW	US New Hampsh	camp
212	Norwalk	MMWR Vol53 SS-8	142			2002	June	Small	none	x										x		GW	US Connecticut	Heavy rains preceded outbreak with unchlorinated well at a camp
213	Naegleria Fowleri	MMWR Vol53 SS-8	2			2002	Oct	Large	none												x	GW	US Arizona	Community, two cases both households tested positive for bacteria

ID#	Microorganism	Source	Confirmed Cases	Deaths	Presumptive Cases	Year	Month	System	Treatment Method	Precipitation	Distribution system	Source contamination	Sewage Contamination	Operator Deficiencies	Failure to Institute protection measures	Treatment Deficiencies	Water Source	Country	Notes
214	Campylobacter	MMWR Vol55 SS-12	110			2003	May	Small	none		x				x		GW	US Washington	Tavellers staying at farm with untreated well water and backsiphonage
215	s. typhi	MMWR Vol55 SS-12			70	2004	Aug	Small	UV disinfection		x					x	GW	US Montana	Restaurant; UV device not working and backsiphonage from poultry pen
216	campylobacter	MMWR Vol55 SS-12			34	2004	Aug	Large	Unspecified		x						GW	US Virginia	Community water supply
217	Campylobacter	MMWR Vol55 SS-12			20	2004	Dec	small	none						x		GW	US Wisconsin	Restaurant
218	campylobacter	MMWR Vol55 SS-12			82	2004	Jan	Large	Unspecified		x						GW	US Ohio	Factory; cross connections with non potable holding tanks on property
219	Norwalk	MMWR Vol55 SS-12			70	2004	Jan	small	unspecified		x						SW	US Pennsylvania	Ski Resort; water line cross connected to unpotable source
220	campylobacter/norwalk	MMWR Vol55 SS-12	25		1425	2004	July	small	none	x	x	x	x		x		GW	US Ohio	Restaurant/bar/camp; ground water for numerous wells was contaminated due to heavy septic use, increased rain fall and cross connections
221	unknown/gastro	MMWR Vol55 SS-12			174	2004	June	small	chlorination				x			x	GW	US Pennsylvania	Camp; sewage leak occurred 1 wk before outbreak and chlorinator was broken
222	Giardia Intestinalis	MMWR Vol55 SS-12			11	2004	June	small	Unspecified		x						GW	US Vermont	Camp

Appendix 3.1: Required Clearance Distances for Sewage Systems in Ontario

Well with watertight casing to a depth of 6m	15m
Any other well	30m
Lake	15m
Pond	15m
Reservoir	15m
River	15m
Stream	15m

Ontario Building Code Act, 1997, 8.2.1.6 (2)

③ Clean Only
BL-10-30