THE CHARACTERIZATION OF SIGNIFICANT DIRECT THREATS TO SOURCE WATERSHEDS: A RISK-BASED APPROACH

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Alicia Kelly, B.Sc., Indiana Wesleyan University, 2002

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Abstract

The Characterization of Significant Direct Threats to Source Watersheds: A Risk-Based Approach

By: Alicia Kelly

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In 2004, the Ontario Ministry of the Environment proposed the *Drinking Water Source Protection Act* which stipulated that, in the development of source water protection plans, significant direct threats to source watersheds are to be identified. Examination of the major risk factors threatening water resources proved there are insufficient scientific data available to regulators to accomplish this task. Research showed *E.coli O157:H7*, *Salmonella*, *Giardia lamblia*, and *Cryptosporidium parvum*, and the sources of these pathogens in the environment are, qualitatively, significant direct threats to water resources. However, a quantitative characterization of significance depends on the failure probabilities of pathogen sources. Using the Ontario Spills Action Center data, the occurrence of failure was found to have a high non-zero probability. However, considerable uncertainties revealed in these data suggest that a better understanding of failure is critical to accurately characterize significant threats to drinking water resources.

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Chapter One: Introduction

1.1 Background

Microscopic in size, yet limitless in capabilities, pathogenic organisms are invisible to the naked eye but have the innate ability to cause disorder and disease. Size, environmental resistance and virulence are the key factors responsible for the threatening nature of pathogens which continue to jeopardize public health by contaminating community water supplies. As end-users of the water distribution system, public citizens depend on government officials, municipal authorities and water treatment plant operators, trusting blindly in the quality of water being received at the tap.

The prevalence of water-borne disease and the vital need to preserve and protect drinking water are long-standing concerns of society. The notion that water can harbor harmful contaminants was acknowledged over 2000 years ago by Hippocrates, 'the father of modern medicine' in his statement that, "we must also consider the qualities of the waters, for as they differ from one another in taste and weight, so also do they differ much in their qualities" (Hippocrates, 400 BC). Following the Cholera epidemic of 1854, Dr. John Snow was the first to prove that water was capable of transmitting human diseases (John Snow Society, 2004). However, at that time, pathogenic microorganisms had not been identified as the underlying cause of water-borne diseases.

The twentieth century was monumental in the advancement of scientific knowledge. Novel technologies and tremendous research progress have bridged epidemiological knowledge gaps, and given rise to a great understanding of microbial pathogens and the pathways taken to transmit disease. The occurrence of waterborne illnesses, in recent decades, has decreased significantly in Canada and in other developed countries due to advances in water treatment practices including the use of filtration and chlorine as disinfection techniques. However, despite this progress, outbreaks from waterborne bacteria and protozoa are still prevalent in this country and continue to threaten human health. In Canada, there are four major pathogens known to persistently compromise the quality of drinking water. These disease-causing organisms include *E.coli O157:H7*, *Salmonella*, *Cryptosporidium parvum*, and *Giardia lamblia*. Most illnesses caused by these organisms have acute effects, but some are chronic, resulting in long-term diseases such as cancer, heart disease, arthritis, and mental disorders, in some instances resulting in death. Given the detrimental consequences associated with pathogen contamination of drinking water, Ontarians have made it clear that clean and safe drinking water is one of the highest priorities in our province today. In fact, approximately 75% of Canadians are very concerned about the quality of their drinking water (Goldfarb Consultants, 2001).

Public awareness and concern over the quality of drinking water in Ontario was compounded by the events of May 2000, when the water supply in Walkerton Ontario became contaminated with *E.coli O157:H7* and resulted in 7 deaths and rendered 2300 people ill. This devastating incident drove the need for more stringent drinking water protection laws, regulations, and practices in Ontario. In response, the provincial government has recently introduced several new pieces of legislation including the *Safe Drinking Water Act (2002)*; the *Sustainable Water and Sewage Systems Act (2002)*; the *Nutrient Management Act (2002);* and the *Drinking Water Systems Regulation (2003)*. However, the implementation of these *Acts* alone has not succeeded in protecting drinking water at its source.

Justice O'Connor suggested that the most efficient way to achieve a healthy public water supply and to prevent water contaminants from infecting people was to utilize multiple barriers (O'Connor, 2002b). Source water protection is crucial to an effective multi-barrier approach to drinking water. The Ontario Ministry of the Environment (MOE) has responded to this urgent recommendation by proposing the *Drinking Water Source Protection Act* which is expected to become law in 2005. This is a critical piece of legislation because it would establish a framework for the development of source water protection plans to ensure that current and future sources of drinking water in Ontario's lakes, rivers, and groundwater are protected from potential contamination. A key part of this proposed Act is the requirement for each source water protection plan to determine significant direct threats to source waters and to act on them. Further, the Technical Experts Committee suggests a risk assessment based approach.

1.2 Research Question and Hypothesis

Can 'significant direct threats' to source watersheds be accurately characterized so that the risks to drinking water are rendered so negligible that a reasonable and informed person would feel safe drinking the water?

Following the Walkerton outbreak, Justice Dennis O'Connor alluded to this question as head of the inquiry to investigate the events leading to this tragedy and to evaluate the state of water quality in Ontario. In his report to the Ontario government, Justice O'Connor emphasized the need to "identify areas where significant direct threats exist to the safety of drinking water as part of a strategy for source water protection planning" (O'Connor, 2002b, p.105). Ultimately, the goal of Justice O'Connor's recommendations was to ensure that "Ontario's drinking water systems deliver water with a level of risk so negligible that a reasonable and informed person would feel safe drinking the water" (O'Connor, 2002b, p.5). This thesis explores these statements, made by Justice O'Connor, and uses a risk-based[1] approach to determine whether a sufficient and holistic characterization of significant direct threats to source water can be understood given current scientific knowledge. The findings gathered by this study will be used to assess whether the Ontario government's upcoming *Drinking Water Source Protection Act* will be able to efficiently identify significant direct threats to source watersheds and sequentially guarantee public health safety. It is hypothesized that significant direct threats to source waters cannot be accurately, and scientifically determined in risk assessment terms given current knowledge.

1.3 Purpose and Objectives

The purpose of this study is to outline the major risk factors which together threaten the quality of water resources. In addition, this paper is intended to assess whether there is enough scientific data available to risk managers (regulators) in order to fully characterize and mitigate significant direct threats to drinking water supplies. This analysis is important because the upcoming *Drinking Water Source Protection Act* is expected to delineate the factors which constitute a significant direct threat to source waters. This study will assess whether the Ontario government can adequately determine significant threats so that source water protection committees can take the appropriate actions to prevent disease causing microorganisms from reaching the tap. The principle objectives of this study include:

1. *To evaluate cross-jurisdictional policies, regulations and strategies implemented throughout Canada and across the globe which focus on drinking water and source water protection.*

The purpose of this objective is to assess whether there have been attempts by other jurisdictions to characterize significant direct threats to source watersheds. This examination is

[1] In the context of this study, a risk-based approach involves an assessment of the threats having a high probability of causing harm to the quality of source waters.

intended to provide guidance into the methods used elsewhere to delineate significant threats to water resources.

2. *To examine current research in order to illustrate the survival characteristics, infection mechanisms and virulent human health capabilities of major waterborne pathogens.*

The purpose of this objective is to identity the waterborne pathogens which persistently invade drinking water supplies and pose the greatest threat to source water in Ontario. This paper focuses on pathogenic threats because this form of contamination is a high risk to human health given past outbreaks of water-borne disease.

3. *To evaluate the sources of pathogen contamination to drinking water supplies.*

The purpose of this objective is to determine the origin of pathogens in the environment and to assess which pathogen sources pose the greatest risk to source watersheds.

4. *To use the Spills Action Center spills database to assess the probability of failure among operations with source water impacts.*

The purpose of this objective is to identify the types and causes of failure common in industrial, agricultural and municipal water systems and to estimate the associated risks to source waters. The assessment of failure probability will be a key factor in the characterization of significant threats to source watersheds.

5. *To assess whether the upcoming Drinking Water Source Protection Act is likely to accurately portray significant direct threats to source watersheds.*

This is the ultimate objective of this study. The achievement of this objective is dependant on the findings deduced in the attainment of objectives 1 through 4.

1.4 Outline

This thesis is composed of seven chapters which are laid out as follows. Chapter Two: Current Studies of Significant Threats to Water and Risk Assessment, discusses the key concepts related to the objectives of this research in existing studies including: the nature of risk and the components of risk analysis, methods used to determine acceptable risk, uncertainty, the Precautionary Principle, the purpose of source water protection, and the meaning of significance. Chapter Three: Jurisdictional Review of Source Water Protection Legislation, reviews the regulations, acts and policies of many jurisdictions to determine whether there have been previous attempts to define 'significant direct threats' to source water resources. The various countries explored in this investigation include Australia, New Zealand, Europe, Ireland, Scotland, the United States of America, and Canada, with specific attention given to British Columbia and Ontario. Chapter Four: Pathogenic Threats to Water Quality, reviews the characteristics of four specific pathogens that are prevalent worldwide and are severe risks to environmental and human health. These hazardous microorganisms include *E.coli O157:H7*, *Salmonella*, *Cryptosporidium parvum*, and *Giardia lamblia*. These pathogens are examined to assess their transport and survival characteristics, as well as their effects on source water protection. Chapter Five: Origins of Pathogenic Threats to Source Watersheds, assesses the sources of pathogen contamination in source waters set out by the Technical Experts Committee as the 'Threats of Provincial Concern'. These sources of risk include storage and land application of biosolids, septage and manure, sanitary sewage and septics, stormwater infiltration, and water treatment plant waste water backwash. Chapter Six: Failure Estimates Using the Ontario Spills Action Center Spills Database, analyzes the SAC spills data from 2003 and 2004 to estimate the failure rates of agricultural, industrial and municipal operations in Ontario resulting in the discharge of pathogens into the environment. This assessment looks particularly at the geographical distribution of spill reports, the types of contaminants spilled, the sources responsible for spill events, the potential causes of failure, and seasonal trends.

Chapter Two: Current Studies of Significant Threats to Water and Risk Assessment

2.1 The Role of Risk Assessment in Determining Significant Threats to Source Watersheds

The Technical Experts Committee, mandated to advise the Minister of the Environment on a 'threats assessment framework' for watershed-based source protection in Ontario, recommended that " 'Significant Direct Threats' should be thought of as 'Significant Risks' because the term implies both high threat and a likely pathway for the threat to reach receiving water" (TEC, 2004, p.23). Therefore, the following sections examine the nature of risk and the analysis methods commonly used to characterize risk. This is critical to comprehending the steps taken and constraints faced by regulators when determining acceptable risks to source water. The following sections of this chapter also examine the existing studies that have attempted to quantify or specify significant risks.

2.1.1 Perceptions of Risk

Essentially, this thesis is focused on determining the risks which threaten source water protection. Therefore, understanding the meaning of risk is a necessity. This concept has intrigued many scientists and researchers in the past, and thus, the idea of risk has been studied extensively. Classically, risk is defined as "the probability of suffering harm or loss" (Mauboussin and Schay, 2001, p.5). However, Covello and Merkhofer (1994) diverged slightly from this interpretation and describe risk as the possibility and uncertainty of the occurrence, magnitude, and timing of an adverse outcome. Another well-known explanation of risk was provided by Kaplan and Garrick (1981) who found risk to be the answer to three questions: what can go wrong? How likely is it? What are the consequences?

The perception of risk varies among regulators, scientists, engineers, academics and the public. Powell (1998) acknowledged that all opinions related to risk are based on individual interpretations of data, taking into account one's own experiences, values and expectations. Psychological research has found several known factors responsible for influencing risk perception (Covello, 1992; 1995). Nineteen of these factors are summarized in Table 2.1.

Table 2.1: Factors Influencing Risk Perceptions

Factors	Conditions Associated with Increased Public Concern	Conditions Associated with Decreased Public Concern
Catastrophic potential	Fatalities and injuries grouped in time and space	Fatalities and injuries scattered and random
Familiarity	Unfamiliar	Familiar
Understanding	Mechanisms or process not understood	Mechanisms or process understood
Uncertainty	Risks scientifically unknown or uncertain	Risks known to science
Controllability (personal)	Uncontrollable	Controllable
Voluntariness of exposure	Involuntary	Voluntary
Effects on children	Children specifically at risk	Children not specifically at risk
Effects manifestation	Delayed effects	Immediate effects
Effects on future generations	Risks to future generations	No risk to future generations
Victim identity	Identifiable victims	Statistical victims
Dread	Effects dreaded	Effects not dreaded
Trust in institutions	Lack of trust in responsible institutions	Trust in responsible institutions
Media attention	Much media attention	Little media attention
Accident history	Major and sometimes minor accidents	No major or minor accidents
Equity	Inequitable distribution of risks and benefits	Equitable distribution of risk and benefits
Benefits	Unclear benefits	Clear benefits
Reversibility	Effects irreversible	Effects reversible
Personal stake	Individual personally at risk	Individual not personally at risk
Origin	Caused by human actions or failures	Caused by acts of nature or God

* Source: Covello, 1995.

Covello (1983) believed that risks with catastrophic potential are of greatest concern to people because they pose a tremendous threat to human survival. Wilson and Crouch (1987) theorized that risk perception is strongly correlated with the way in which risks are calculated. Accordingly, risks based on historical data, sound scientific study, and well understood processes are commonly perceived reliably. Other events identified by Aakko (2004) and Covello (1995) that contribute to risk perception include the severity or threat of a hazard, past events and the forecasting of future events, and hazards receiving extensive media coverage. Aakko (2004) used the Chernobyl and Three Mile Island nuclear accidents as examples of how broad media attention increased global fear of nuclear power. Rizak and Hrudey (2005) conducted a survey to determine the extent to which experts in various environmental fields share similar beliefs and conceptual frameworks in regard to environmental health risks. The results indicated that obvious discrepancies exist with respect to risk perceptions even between members of a particular field of study. This finding is one of many reasons why there is a growing distrust of experts and science by the public (Powell, 1998). Given the complex array of risk views amongst all members of society, the need for reliable and effective risk analysis techniques is essential to accurately judge the potential hazards associated with particular risks.

2.1.2 Risk Analysis: An Essential Process for the Characterization of Risk

The Advisory Committee on Watershed-Based Source Protection Planning, established by the Ontario Ministry of the Environment in 2002, recommended that the Ontario government should "promote the development of a state-of-the-art risk management process by committing to continuous improvement and using the best available science to evaluate the potential impact of threats to drinking water" (Advisory Committee, 2003, p.35). This statement implies that risk analysis and the determination of significant risks is a fundamental part of source water protection planning. The process of risk analysis involves a detailed examination of the events performed in order to quantify the probabilities and expected consequences of identified risks to human life, health, property, or the environment (Society for Risk Analysis, 2003). The 'Red Book', published by the U.S. National Research Council in 1983, first formalized the division of the risk analysis model into three different stages. These stages include risk assessment, risk management and risk communication. All of these processes are critical in the accurate characterization of risk.

Hrudey (1997) suggested the goal of risk assessment is to provide sufficient understanding of the dimensions and character of risk to help us recognize the nature of the tradeoffs which must be made to manage risk in the face of uncertainty. Several techniques have been studied and used for the assessment of risk. The comparison of risks is one method used in risk assessment to evaluate the magnitude of risks. Comparative Risk Assessment (CRA) ranks risks, highest to lowest, on the basis of their average annual probability of inducing (human) fatality as a way to encourage more rational and consistent risk decisions (Shrader-Frechette, 1995). However, CRA is difficult due to the lack of reliable event frequency data and the high costs of hazard testing needed for this risk assessment method. Shrader-Frechette (1995) also pointed out that CRA ranking is unrealistic because it assumes that death is the only important 'end point' of risk, and does not consider human health, ecology and environmental welfare as important variables when comparing risks. Wilson and Crouch (1987) also agree that it is problematic and misleading to treat all risks of similar numerical magnitude the same. These authors suggest that in some cases it may be useful to contrast risks in order to convey the different ways in which they are treated in society.

Bier (1999) believes that Probabilistic Risk Analysis (PRA) is a risk assessment method needed when estimating the frequencies of accidents in complex engineered systems such as nuclear power plants, where the number of actual accidents is finite (commonly between 0 and 2) and where conventional statistical techniques are insufficient. Unfortunately, the use of PRA is faced with two major challenges: (1) its reliance on subjective judgment and (2) the difficulty in accounting for human performance (such as error, management and organizational factors) in PRA models. Despite these set-backs, PRA is being productively used in various disciplines and is becoming increasingly more valuable in regulatory decision making.

According to the United States Environmental Protection Agency (USEPA), cumulative risks[2] are an important concern to the American public. Therefore, Cumulative Risk Assessments are proposed as the best available tool to address certain questions dealing with multiple-stressor impacts (USEPA, 2003a). Currently, most assessments conducted for the evaluation of multiple stressors, are examined individually and presented as if the others were not present. Regretfully, the USEPA (2003a) has admitted that due to present scientific limitations, cumulative risk assessments performed today would be unable to adequately answer all the questions posed by stakeholders or interested parties. Given the limitations in not having clear risk assessment methods, the Technical Experts Committee in Ontario (2004) recommended that a semi-quantitative approach is the most practical and efficient method for obtaining a consistent approach to assessing risks to Ontario watersheds.

Overall, risk assessment, in all forms, increases the reliability of evidence used for risk management decisions. Therefore, this important risk analysis step should be used as a tool for informed risk decision-making in risk management strategies (Hrudey, 1997). In contrast to risk assessment, risk management allows for the incorporation of non-scientific factors into policy decisions (Powell, 1998). Hill (2001) stated that the management of risk strives to improve decision making under uncertainty as a means of maximizing benefits and minimizing costs.

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[2] Cumulative risks are defined as "the combined risks from aggregate exposures to multiple agents or stressors" (USEPA, 2003a).

This author also explained that this process frequently necessitates the involvement of tradeoffs, by which potential benefits of actions and innovations are weighed against their potential costs.

The Canadian Standards Association Risk Management Standard (CSA-Q850) was designed to provide a systematic method for identifying, analyzing, evaluating and controlling risk (Wright, 1996). However, at present this standard remains only a guideline. In addition to the CSA Risk Management Standard, many frameworks exist guiding practitioners in the management of risks within Canada including, but not limited to, the Canadian Institute of Chartered Accountants' Criteria of Control Model, the Risk Management in Public Policy Framework created by the Assistant Deputy Minister Working Group on Risk Management, and the Treasury Board's Integrated Risk Management Framework. Hrudey (1997) wrote that although the goals for risk management are eminent, the achievement of more effective risk management has been progressively slow. In anticipation of the upcoming Ontario *Drinking Water Source Protection Act*, the Technical Experts Committee recommends that source protection planning committees develop an 'outcome-based' approach to risk management (Technical Experts Committee, 2004). In order to fulfill this recommendation, local committees will need to develop their own action plans to accomplish their risk management goals. The Technical Experts Committee also emphasizes that it is the responsibility of the province to define its expectations of what source protection planning is sought to achieve, so that local committees can reach provincial objectives.

The decision-making process of risk management has become increasingly more public in democratic societies. Consequently, the reliance on risk communication is of great importance to the risk analysis process. The concept of risk communication evolved in the 1980s as a means of addressing public concern over hazardous wastes at Superfund[3] sites (Aakko, 2004). Covello et al. (2001) expressed that effective communication is critical to the successful resolution of any type of health, safety, or environmental controversy. Risk communication is defined by the U.S. National Research Council Committee on Risk Perception and Communication (1989) as the interactive process of exchanging information and opinion among individuals, groups and institutions. Risk information can be exchanged by various means such as media reports, warning labels, or public meetings involving representatives from government agencies,

[3] Superfund is a federally funded program in the United States, created in 1980, to pay for the investigation and cleanup of the largest and most contaminated sites in the U.S. The USEPA administers the Superfund program (Oregon Department of Environmental Quality, 2005).

industry, the scientific community, the media, and the public (Covello, 1995). Powell (1998) believes the main driving factors contributing to the need for risk communication to include:

- legislative accountability of the government to inform the participatory democracies;
- the desire to overcome opposition to decisions;
- the desire to share power between government and public groups; and
- the desire to develop effective alternatives to direct regulatory control.

The conventional risk communication model, as described by Aakko (2004), involves messages about a crisis or health risk flowing one-way. Essentially this kind of communication style is used to warn people or invoke behavioral change. However, recent years have seen a paradigm shift in this communication model. Risk communication now strives to be a two-way process involving conflict resolution and active public participation (Aakko, 2004).

Arkin (1989) wrote that creating an accurate and comprehensive risk message is one of the greatest challenges of risk communication. The difficulty of clear risk communication is amplified by the presence of multiple publics with fluctuating moods, inconsistent perceptions throughout the population, and views which are not easy to determine (Middlekauf, 1989). Effective risk communication is further inhibited by confusing, complex scientific messages, uncertainty, and lack of trust by the public in the source of the information. As discussed previously, the discrepancies in risk opinions between experts and the public greatly complicate effective risk communication. In addition, Catania (2003) reveals that risk communication is largely impeded by the speed of change and advancement in science and technology. The public's confidence in these areas is declining rapidly due to lack in comprehension and fear of the unknown.

Regardless of the challenges associated with risk communication, the public has the right to know and must be informed of potentially threatening health, safety or environmental issues. In order to combat the barriers to successful risk communication, particular elements must be incorporated into the preparation and articulation of risk messages. Trust is essentially the keystone of effective risk communication. Aakko (2004) proposes four characteristics that effective spokespeople must exhibit in building and maintaining trust, including:

- caring and empathy;
- dedication and commitment;
- competence and expertise; and

- honesty and openness.

The Walkerton outbreak of 2000, and continuous boil water advisories and beach closures throughout Ontario, have contributed to the erosion of trust in regulators of source water protection among Ontarians. Covello (1995) found that when trust and credibility are low, the communicating organization or individual should direct their actions and messages to enhance trust and credibility rather than focusing on the transfer of technical information and fears. Powell (1998) also drew attention to the need for risk messages to be personalized enough to satisfy the concerns of each member of the target audience. Another key element of effective risk communication requires spokespeople and experts to evaluate their own knowledge and understanding before conveying risk information to public stakeholders. Jasanoff (1987) contended that experts themselves need to be educated about their own biases. With respect to science and technology, the public has the right to expect an explanation from risk managers as to how society will be affected by innovation (Catania, 2003). Hance et al. (1989) expressed that proper risk communication must be supported by all levels of the risk management agency. These authors felt that this aids technical and policy staff to interact effectively with communities and to help policy makers determine the appropriate time and method for including the public in decision-making (Hance et al. 1989).

On occasion, the achievement of efficient risk communication is unable to reduce conflict or abridge risk management. Powell (1998) revealed that the success of risk communication can only be measured to the extent that it raises the level of understanding of relevant issues or actions, and satisfies the questions and concerns of those involved within the limits of available knowledge. Risk communication is critical between risk assessors, risk managers and those affected by risks in order for the reduction or aversion of hazards. Throughout the planning and risk analysis processes of source water protection, clear and effective communication must be engaged between government officials, source protection committees and boards, and the public in order to establish trust, increase awareness and enhance involvement among all stakeholders. In the context of this study, perceptions of risk in Ontario will play a key role in how significant threats to source waters are managed. At present, a risk analysis method for significant direct threats is lacking and if significant risks are dealt with in ways other than exclusion, effective risk communication will be imperative.

Understanding the concepts of risk analysis, assessment, management and communication are important to this study because these practices are fundamental to any risk-based approach to the characterization of threats. Further, it is important to recognize that regulators and managers are obligated to use these risk practices when determining significant direct threats to source watersheds.

2.1.3 The Determination of Acceptable Risk

Research has repeatedly observed that there is no such thing as zero risk. Consequently, risks are inherent to modern society and can never be eliminated from life. However, too much weight is often placed on low, involuntary risks while larger, voluntary risks are ignored (Zeckhauser and Viscusi, 1990). Further, Zeckhauser and Vicusi (1990) found that human beings generally overestimate the likelihood of low probability events (such as terrorism), and underestimate higher risks (such as death by automobile accidents or disease). Efficient risk management requires regulators, engineers, scientists and the public to determine which risks, in respect to quality and quantity, deserve regulatory consideration and which are small enough to be deemed acceptable. Cohen (2001) described three frameworks used by the U.S. regulatory system to develop and determine standards of acceptable risk. These frameworks are as follows:

- Decision Theory: prescribes that the benefit of reduced risk be compared to the costs associated with reduction and control measures;
- The Precautionary Principle: calls for the prevention of unnecessary risks (this concept will be discussed in detail in Section 2.2); and
- Cognitive Risk Perception Theory: describes those attributes of a risk, other than its magnitude, that influence the public's tendency to either accept that risk or demand its removal.

With regards to microbial risks from drinking water, the USEPA developed the *National Primary Drinking Water Regulations* (2002c) in accordance with the *Safe Drinking Water Act* (1996). These regulations set standards, more specifically Maximum Contaminant Levels (MCLs), for microbiological organisms in drinking water over which the contaminant would be considered unacceptable. For example, the MCL for *Giardia lamblia* is 99.9% inactivation. If fewer than 99.9% of these organisms are inactivated during treatment, the final drinking water would be deemed unacceptable and thus unsafe for public consumption.

The concept of 10^{-6} has been used as a criterion of acceptable risk for decades. In relation to human health risks, Kelly (1991) described 10^{-6} as a shorthand representation of an increased lifetime chance of 0.000001 in 1 or one chance in a million of developing cancer due to lifetime exposure to a substance. In the United Kingdom, this figure is based on an annual risk from exposure as opposed to a lifetime risk (Hunter and Fewtrell, 2001). The origin of 10^{-6} is unclear, however, records show that it was originally an arbitrary number adopted by the U.S. Food and Drug Administration in the 1970s as a screening level of 'essentially zero' or *de minimus risk* (Kelly, 1991). Kelly (1991) traced the origin of 10^{-6} back even further to a 1961 proposal by two scientists from the National Cancer Institute regarding methods to determine safety levels in carcinogenicity testing. In the past, *de minimus risk* has been almost entirely applied to hazardous wastes, pesticides, and selected carcinogens, but not to air, drinking water, or other sources perceived to be lesser risks. Although this number has been used extensively within the United States to guide acceptability in regard to hazardous waste sites, it has never been mandated in any EPA regulations (Kelly, 1991). Yet, in 1990, the EPA Superfund legislation codified the target range of 10^{-6} to 10^{-4} as a range of 'generally acceptable risk' as part of the National Contingency Plan (NCP) (Kelly, 1991). Kelly (1991) believed that using arbitrary thresholds of acceptable risk, such as 10^{-6}, is not a sound solution to managing the public's perception of risk. Instead, the process in which risks are assessed and managed should be standardized and increased efforts should be taken to narrow the gap between the public's comprehension of actual versus perceived risk.

The development of an acceptable level of risk is difficult because it needs to encompass the views and opinions of all stakeholders including government officials, scientists, designers, operators and the public. Fischhoff (1994) described a survey conducted by the USEPA which found that no standard level of risk could be recognized as acceptable in all cases and under all regulatory programs because the acceptability of risk is a relative concept and involves consideration of many different factors. In light of this, the Pareto Improvement Principle may be seen as the best method for identifying acceptable levels of risk. This principle holds that an action is acceptable if the majority of benefits are great enough that those who 'win' from the action could compensate those who lose (Fischhoff, 1994). However, Fischhoff (1994) argued that the losers in these situations would likely fail to see the efficiency in this principle or would not 'win' often enough to see the justification. All organizations and individuals, by nature, expect to be compensated and accounted for in all situations, especially those involving risk.

Hunter and Fewtrell (2001) described 6 approaches to the determination of acceptable risk which include the Predefined Probability Approach, the Currently Tolerated Approach, the Disease Burden Approach, the Economic Approach, and the Political (Bargaining) Approach. These approaches are explained in detail in Appendix 2.1. Source water protection seems to take all of these approaches to acceptable risk determination into account, making the identification of acceptable risks a daunting task. Although expert knowledge and risk analysis methods are assumed to be the most accurate, sufficient uncertainty lies in the processes and models used by experts. Hunter and Fewtrell (2001) suggest that public health professionals and agencies such as the World Health Organization have a crucial responsibility to represent the interests of the socially excluded in policy decisions where these decisions are likely to impact directly or indirectly on health. Challenges associated with defining acceptable risks exist, but they can be overcome if individuals and organizations are open to the views of all involved and accept the reality of absolute uncertainty.

2.1.4 Risk in the Face of Uncertainty

Covello and Merkhofer (1994) described risk as a combination of something that is undesirable and uncertain. This description conveys the inherent relationship between risk and uncertainty. Consequently, when assessing, managing and communicating risks there should be sufficient consideration of the associated uncertainties. The USEPA defines uncertainty as "a lack of knowledge about certain factors in a study which can reduce the confidence in conclusions drawn from data in that study" (USEPA, 2005c). Morgan and Henrion (1990) found that in the past, the presence of uncertainty in policy analysis was ignored. These authors suggest that uncertainty should be recognized and confronted in the following situations:

- when performing an analysis in which people's attitudes toward risk are likely to be important;
- when performing an analysis in which uncertain information from different sources must be combined; and
- when a decision must be made about whether to expend resources to acquire additional information.

Today, scientists and regulators have grown accustomed to dealing with uncertainties in the decision making process, yet they have difficulties communicating and explaining these uncertainties to the public. Hance et al. (1989) stressed the importance of acknowledging uncertainty and emphasized that risk analysts should be specific about what they are doing to find the answers, and to the greatest extent possible, should involve people in finding the answers.

Hrudey (1997) identified and commended the recent differentiation in uncertainty between variability and true uncertainty. He explains that variability for any risk parameter indicates that there are true values for that parameter (such as an individual's age). In addition, variability applies to all stages of data collection and modeling. In contrast, true uncertainty is recognized as a parameter which has a single value, but that the true value is not known. Finkel (1990) identified three main categories of true risk uncertainty which include:

- Parameter Uncertainty: Attributed to uncertainty in model parameter estimations due to measurement and sampling error or from systematic uncertainty due to biased sampling or improper model design.
- Model Uncertainty: Attributed to the limited ability of mathematical models to accurately portray reality. Errors often caused by insufficient theoretical knowledge of the structural and operational characteristics of models.
- Decision Rule Uncertainty: Attributed to inaccurate or inappropriate definitions for desired outcome criteria, value parameters, and decision variables. For example, the monetary value calculated to represent the loss of life.

The characterization of variability and true uncertainty are critical parts of both risk assessment and risk management. Yet, Finkel (1990) warned that research efforts in risk analysis should be geared towards understanding uncertainties and less concerned with reducing them. Further, Wilson and Crouch (1987) believed that the advancement of knowledge and technology will not eradicate the existence of risks and uncertainties, but will only change their characteristics. Source water protection planning is faced by all of these types of uncertainty, which contributes to the difficulty of specifying significant direct threats to source water resources. Given the uncertainties in pathogen survival and transport, and the uncertainties in the analysis of risks to source water from significant threats, precaution must be used in the process of source water protection planning.

2.2 The Need for Precaution in the Analysis of Risks

In dealing with scientific uncertainty in risk analysis, Justice O'Connor (2002b) encouraged those developing source water protection plans to err on the side of safety. Further, the absence of scientific certainty about risk requires that precautionary measures be taken in the face of irreversible harm. This concept is the basis of the Precautionary Principle which has become internationally known and adopted by many countries as a condition of, but not restricted to, environmental law. In fact, the Technical Experts Committee recommends that source water protection plans be based on the Precautionary Principle when the risk of a significant threat to source water cannot be estimated (TEC, 2004).

The Precautionary Principle was first established in the 1987 twenty-four-nation treaty known as the Montreal Protocol on Substances that Deplete the Ozone Layer. Since then, it has been incorporated into numerous international environmental treaties and declarations including the 1992 Rio Declaration on Environment and Development, the 1990 and 1992 Global Climate Change Conferences, the 1992 Convention on the Protection of the Environment of the Northeast Atlantic and the 2000 Biosafety Protocol of the Cartagena Convention. However, the interpretation of the Precautionary Principle differs considerably. The most commonly recognized version of this principle is enclosed in the 1992 Rio Declaration on Environment and Development which supports the use of the Precautionary Principle,

> "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (United Nations Conference on Environment and Development, 1992).

This adaptation of the Precautionary Principle suggests that the acceptability of a risk depends on the technological and economic feasibility of mitigating adverse impacts that may result from a product or technology (Cohen, 2001). This approach to the Precautionary Principle is consistent in Canadian practice and is reflected in Canadian environmental legislation, such as the *Canadian Environmental Protection Act* (Government of Canada, 2001). The 1998 Wingspread Conference on the Precautionary Principle offered a different definition:

> "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically" (Wingspread Conference, 1998).

This interpretation expands the purpose of the Precautionary Principle to include the protection of human health, in addition to the environment. Regardless of the discrepancies associated with defining the Precautionary Principle, Myers (2000) explained that there are three additional goals, beyond 'harm' and 'scientific uncertainty', universal to this principle:

- the attempt to seek alternatives to harmful technologies;
- shifting the responsibility for demonstrating its safety to the proponents of the technology; and
- transparency and democracy in making decisions about technologies.

Catania (2003) concluded that the ultimate role played by the Precautionary Principle is based on the values and priorities of a region, nation or continent.

The Precautionary Principle is commonly misinterpreted as being anti-science (Grandjean, 2005). Myers (2000) explained that this assertion is based on two flawed assumptions, the first being that those who advocate precaution urge action on the basis of vague fears, regardless of whether there is scientific evidence in support their fears. The second misconception is the belief that taking action, by employing the Precautionary Principle, in advance of full scientific proof undermines science (Myers, 2000). De Jaegher (2004) argued that the Precautionary Principle does not exclude science, but rather goes beyond it by offering a new way of thinking, a new model, aiming to embrace the complexity of the new economy. Similarly, this principle compels the need for changes in science calling for the extraction of evidence from multiple disciplines, improved clarity about uncertainties, better anticipation of harm, and the increased identification of solutions (Tickner and Myers, 2000). The Precautionary Principle is not meant to replace scientific knowledge, however practicing precaution is a way to avoid the fallible tendencies that are habitual in science. Truly, science and the Precautionary Principle are both crucial in risk analysis and when used together enable the safest and most effective risk decisions.

O'Connor (2002b) emphasized that the Precautionary Principle and risk management are complementary, and the need for precaution rises when uncertainties about specific hazards are expected to persist and where the suspected adverse effects may be serious or irreversible. It was also stated in the Maastricht Treaty on the European Union that community policy on the environment should be based on the Precautionary Principle and that environmental damage should be prevented at the source (European Commission, 1992). Given the vulnerability of source watersheds to pathogen contamination, precaution must be exercised when analyzing the severity of potential risks. In recognition of this necessity, The Technical Experts Committee (2004) recommended to the Ontario government that in keeping with a precautionary approach, where local committees identify significant risks that have the potential to create a large impact, actions to mitigate the risks should be undertaken as quickly as possible. In addition, this Committee supported the application of the Precautionary Principle to pathogens, which may change over time and can be difficult to assess (TEC, 2004).

2.3 Source Water Protection

In Ontario, the critical need for source water protection practices and regulated policies was motivated by the unforgettable incident of May 2000 when the drinking water in Walkerton Ontario became contaminated with life-threatening bacteria, predominantly *E.coli O157:H7.* This devastating event resulted in 7 deaths, severe illness of 2,300 people, and a community filled with feelings of anger, frustration, and insecurity (O'Connor, 2002a). This incident was primarily caused by a torrential downpour washing bacteria-laden cow manure into poorly planned and maintained community wells (Vokey, 2002). The incompetence of two key Walkerton Public Utilities operators contributed to the outbreak through a series of misdemeanors including the failure to adequately chlorinate the water, false reporting, and improper treatment and monitoring practices as laid out by the provincial government.

Justice Dennis O'Connor was appointed to head the public inquiry to investigate the events leading to the Walkerton outbreak, to identify the role played by the government, and to evaluate the overall safety of drinking water in Ontario. The results of this investigation were written up in Justice O'Connor's Reports on the Walkerton Inquiry in which he made 121 recommendations to the government of Ontario. In the reports, Justice O'Connor specifically called on the Ontario Ministry of the Environment (MOE) to be the lead provincial agency in providing safe drinking water and recommended that the province develop a comprehensive source-to-tap, government-wide drinking water policy.

It has become apparent that the best way to ensure the safety of drinking water is through a multiple barrier approach that starts with the protection of source water (Advisory Committee on Watershed-Based Source Protection Planning, 2003). O'Connor (2002b) concedes that the most efficient way to achieve a healthy public water supply is to utilize multiple barriers to prevent water contaminants from reaching people. The drinking water system affected by the multi-barrier approach includes the source watershed, the drinking water treatment plant, and the distribution system. The barriers used in this approach can be physical, such as the installation of filtration devises within a drinking water treatment facility, or they may take the form of processes or tools employed to improve the overall management of a drinking water program, such as standards, policies, training programs and communication strategies (F/P/T Subcommittee on Drinking Water and the CCME, 2004a). The White Paper on Source Protection Planning (2004c) developed by the MOE identified the five types of barriers commonly used in the provision of drinking water within Ontario and across international jurisdictions as:

- Source Protection: this barrier strives to keep the raw water[4] as clean as possible to lower the risk that contaminants will get through or overwhelm the treatment system.
- Treatment: Involves one or more processes to remove or inactivate contaminants.
- Distribution System Security: Prevents contamination and ensures an appropriate free chlorine residual throughout.
- Monitoring Programs: Used to detect contaminants that exist in concentrations beyond acceptable limits and to return systems to normal operation.
- Responses to Adverse Conditions: Include emergency responses and are required when other processes fail or in cases where there are indications of deteriorating water quality.

Each of the barriers described offers some level of protection, yet, each barrier is not 100% effective alone. Thus, O'Connor (2002b) stressed that an over-reliance on a single barrier compromises the effectiveness of the other barriers and consequently increases the risk of contamination. The major strength of using multiple barriers simultaneously is that the limitations or failure of one or more barriers may be compensated for by the effective operation of the remaining barriers (F/P/T Subcommittee on Drinking Water and the CCME, 2004a).

O'Connor (2002b) recommended that drinking water sources be protected by developing watershed-based source protection plans. He also advised that these plans are required for all watersheds throughout Ontario. Drinking water source protection planning must take place at

[4] Raw water is defined as water in its natural state, prior to treatment for drinking (F/P/T Subcommittee on Drinking Water and the CCME, 2004a).

the watershed level because it allows a water resource system to be considered in its entirety, and is not limited to municipal boundaries (Advisory Committee, 2003). Presently, source protection planning is carried out on a voluntary basis by municipalities and conservation authorities, which leads to inconsistencies throughout the province (Ontario Ministry of the Environment, 2004c). This is largely due to the absence of specific legislation that focuses on source water protection and planning in Ontario. However, the provincial government has released a proposed *Drinking Water Source Protection Act* which is expected to become legislation at some point in 2005. This *Act* will be examined further in Chapter Three in addition to other laws and policies applied to drinking water quality in Ontario and other jurisdictions.

The Technical Experts Committee (2004) stated that the source protection planning process is designed to enable a local Source Protection Planning Committee to evaluate the vulnerability of drinking water source areas. Section Two of the proposed *Drinking Water Source Protection Act* suggests that the establishment of source protection areas in Southern Ontario will be synonymous with the areas over which a Conservation Authority has jurisdiction (Government of Ontario, 2004). Therefore, Conservation Authorities will play a central role in the source water planning process. The proposed *Act* also states that a Source Protection Committee must create a terms of reference to define each watershed in the source protection areas for which an assessment report and source protection plan (SPP) will need to be prepared (Government of Ontario, 2004). The Ontario Ministry of the Environment (2004c) explained that the development of a SPP would involve evaluating management options based on the ranked hazards set out by a source water protection assessment, followed by prioritizing and implementing appropriate actions. All SPPs would have to adhere to a consistent provincial standard set through regulations but the content requirements are expected to be flexible enough to accommodate local conditions that will vary between watersheds (MOE, 2004c). O'Connor (2004) insisted that the planning process for source watersheds be completely transparent to the public in order to ensure that their concerns are considered and addressed and to encourage community acceptance of the watershed management plan.

Effective source protection planning would identify areas where threats to drinking water sources exist (Advisory Committee, 2003). Qualitative and quantitative threats to surface and groundwater sources may be natural or created by human activities (MOE, 2004c). The Advisory Committee on Watershed-Based Source Protection Planning (2003) added that a threat may originate from a point or non-point source, which will be differentiated in Chapter Five, and can be intentional or unintentional. The Federal-Provincial-Territorial Committee on Drinking Water and the CCME (2004a) explained that the characterization of these potential threats is achieved through a source water assessment which is an essential component of a source water protection strategy. Environment Canada (2001) in partnership with the National Water Research Institute identified a list of 13 water quality-related threats to sources of drinking water. Pathogenic organisms were among the threats on this inventory and are expected to continue to emerge as a growing problem in Canada and across the globe. The growth in human population densities, along with rapidly expanding and increasingly intensive livestock/poultry operations, pose significant animal and human waste management challenges which are partially responsible for the increased risk of pathogenic threats to source watersheds. These threats to drinking water sources are explored in Chapter Four.

Incidents of water-borne disease outbreaks, such as the Walkerton tragedy, have not been limited to Ontario. Pathogen contamination of drinking water supplies is a national and international concern. Water treatment alone can not provide the assurance of high quality water. Even with the most expensive technology, a community is not safe from water contamination if protection does not start at the source (MOE, 2004c). Source water protection is only one barrier in a series of multiple barriers which together create a holistic and proactive strategy for safeguarding drinking water. In addition to the protection of human health, a myriad of benefits are generated by the multi-barrier approach including the reduction in health care costs, better management of water treatment costs, and increased environmental protection. The success of source water protection strategies depends on the commitment and cooperation of all stakeholders including regulators, operators, municipalities, conservation authorities and members of the community. It also necessitates a reliance on the Precautionary Principle when making risk decisions. The protection of drinking water at its source is just the first barrier in a multi-barrier system that helps to ensure a long-term supply of safe, clean drinking water (Advisory Committee, 2003).

2.4 The Meaning of Significant

In the Report on the Walkerton Inquiry, Justice O'Connor recommended that "where the potential exists for a **significant** direct threat to drinking water sources, municipal official plans and decisions must be consistent with the applicable source protection plan" (O'Connor, 2002b, p.113). In this context, the use of the term significant as an adjective of threats is arbitrary because it is not definitive and its value is judgment-based. Lawrence (2003) confers that the interpretation of significance involves subjective judgments about importance. Thus, the primary focus of this study is to understand the meaning of the term 'significant' and to determine the factors which contribute to its use as a description of threats to source watersheds. This is not an easy task considering that there is insufficient research concentrated on defining significance. Yet, there have been a few attempts at characterizing this concept.

In response to Justice O'Connor's recommendation that significant risks be assessed and incorporated into source water protection plans, the Technical Experts Committee (2004) compiled a potential definition for significant risk. In their expert opinion, a significant risk is one that has a high likelihood of:

> "rendering a current or future drinking water source impaired, unusable or unsustainable; or compromising the effectiveness of a drinking water treatment process, resulting in adverse human health effects" (TEC, 2004, p.45).

ICF Consulting (2004) perceived significance as a conclusion about whether the observed or estimated changes are considered 'adverse'. The evaluation of the degree of adversity should take into consideration the nature and intensity of effects, spatial and temporal scale, and the potential for recovery (ICF Consulting, 2004). Storey (2005) described significance as a relative concept which reflects the degree of importance placed on the impact in question. This author studied the use of the word significant in the context of adverse environmental impacts and found that five criteria must be taken into account when determining significance:

- Magnitude: severity of the potential effects;
- Duration and Frequency: long- or short-term and frequent or infrequent effects;
- Geographical Extent: assessment of the localized or widespread effects;
- Ecological Context: considers whether the effects occur in areas that have already been adversely affected by human activities and/or are ecologically vulnerable; and
- Reversibility: the effects are either reversible or irreversible.

These criteria imply that sufficient, relevant, and accurate data must be available in order to establish an appropriate delineation of significance. Methods of determining significance often use environmental standards, guidelines or objectives established by federal, provincial or other organizations (Storey, 2005). Storey (2005) explained that if the effects have a high potential to exceed the established level set by the governing body, it may be considered significant.

The application of 'significance' is important to social, economic, ecological and environmental impacts and issues. Lawrence (2003) stated that social and economic significance is an anthropogenic concept. He also suggested that they are normative, contingent on values and entail considering trade-offs. Lawrence (2003), supported by the Canadian Environmental Assessment Agency, studied significant social and economic impacts in environmental assessments. This study found that a variety of methods may be employed to facilitate social and economic impact significance determinations including thresholds and criteria types, technical and support methods, and participation approaches. In addition, significance determination approaches are likely to be more effective if the public understands, actively participates and supports the process, and if considerations for determining which methods, and combinations of methods, are appropriate in any given situation are systematically applied (Lawrence, 2003). Lawrence (2003) perceived that, in general, a significance determination framework should encompass legal parameters, scientific knowledge, good practice, and an acknowledgement of the limits of knowledge and action.

The definition of significance is not well distinguished and appears to be relative to the situation in which it is being applied. For this reason, the determination of significance is frequently left to the judgment of experts and professionals. The limited approaches to significance determination, described above, suggest that with respect to threats to source watersheds, significance is a qualitative interpretation that requires both the qualitative and quantitative assessment of potential effects. In the absence of data or with the uncertainty of available data, the characterization of significance can not be precisely established.

Chapter Three: Jurisdictional Review of Source Water Protection Legislation

3.0 An International Examination of Current Legislation

There is a great amount of knowledge that can be taken from decisions and experiences in other jurisdictions. Clear and well-informed decisions rely partially on the examination of pertinent decisions made by other parties. With this in mind, the purpose of this chapter is to review the regulations, acts and policies of various international jurisdictions to examine previous attempts to define a 'significant direct threat' to source water resources. Throughout this investigation an effort is made to highlight the main legislative documents governing drinking water quality and source water protection in order to illustrate the level of attention given to water resources within each jurisdiction. The spectrum of countries examined for this assessment included Australia, New Zealand, Europe, Ireland, Scotland, the United States of America, and Canada. The scope of this review was based on the Source Water Protection and Pathogens Jurisdictional Review Table (2004) developed by the MOE Source Water Protection Sub Committee, Pathogen Working Group.

See Appendix 3.1 for the summary of cross-jurisdictional legislation for drinking water and source water protection.

3.1 Australia

Australia is one of the world's most developed countries and a federated union of seven states and territories. The *Australian Constitution (1901)* is the authoritative document which divides the Australian continent into its designated states/territory; New South Wales; Queensland; South Australia; Victoria; Western Australia; Tasmania; and the Northern Territory. This nation has a scarce supply of fresh water and 70 percent of its landmass is classified as desert.

The most relevant legislation related to the protection of water quality is at the state/territory level. Unfortunately, state laws are minimal in providing assurances for drinking water quality and are generally concerned with overt pollution rather than quality control (Moeller, 2001). *The Victorian Health (Quality of Drinking Water) Regulations (1991)* was the first water quality regulation in the entire country which required the mandatory monitoring of water supplies for microorganisms. In 1995, The Australian & New Zealand Environment and

Conservation Council (ANZECC) released The National Water Quality Management Strategy: Guidelines for Groundwater Protection in Australia which provided a national framework for the protection of groundwater from contamination. This Strategy also applied to the country of New Zealand. Even though this document proposes controls to reduce loadings to source water, minimum protection zones, and levels of action to reduce groundwater contamination, it does not address pathogens and is not legally enforced. Later, in 1996, the Agriculture and Resource Management Council of Australia and New Zealand in collaboration with the National Health and Medical Research Council created another voluntary framework called The National Water Quality Management Strategy: Australian Drinking Water Guidelines (amended in 2001). The purpose of this framework was to provide guidance on what constitutes good quality drinking water and acts as a reference for identifying acceptable quality of water through community consultation. This document does address the risk of pathogenic organisms and recognizes catchment protection as a vital step in a multiple barrier approach for the protection of drinking water supplies. However, the guideline values for coliforms[5] only apply to the quality of water at the 'point of use' and not at the source.

Only recently has attention been given to the concept of significant risk by the Australian government. The *Environment Protection Act (A1997-92)* was enacted by the Australian Capital Territory (ACT) to provide environmental protection and for related purposes. In Section 3 of this Act it is stated that,

> "the particular objects of this Act are – to establish a process for investigating and where appropriate, remediating land areas where contamination is causing or is likely to cause –
> (i) a significant risk of harm to human health; or
> (ii) a significant risk of material environmental harm or serious environmental harm" (Australian Capital Territory, 1997, 3.1.qa).

Unfortunately, this Act does not further define what constitutes a significant risk.

In June 2004, the Government of Western Australia published the Water Quality Protection Note: Land Use Capability in Public Drinking Water Source Areas. This report sets out to provide advice on the acceptability of land uses and activities within Public Drinking Water Source Areas (PDWSA). In doing so, land uses are categorized as either Incompatible, Compatible with Conditions or Acceptable. In addition, this document also sets out three risk

[5] Guideline suggests that there should be no coliform organism per 100 mL sample of water.

assessment-based priority classification areas and two types of protection zones (see Tables 3.1 and 3.2).

Table 3.1: Priority Classification Area Descriptions

Priority Classification Area	Description
Priority 1 (P1)	These classification areas are managed to ensure that there is no degradation of the drinking water source by preventing the development of potentially harmful activities in these areas. Yet, these harmful activities are not defined. This is the most stringent priority classification for drinking water sources. P(1) areas normally encompass land owned or managed by State agencies, but may include private land that is strategically significant to the protection of the drinking water source (e.g. land immediately adjacent to a reservoir). Most land uses create some risk to water quality and are therefore defined as "Incompatible" in P1 areas.
Priority 2 (P2)	These classification areas are managed to ensure that there is no increased risk of water source contamination/ pollution. For P2 areas, the guiding principle is risk minimization. These areas include established low-risk land development (e.g. low intensity rural activity). Some development is allowed within P2 areas for land uses that are defined as either "Compatible with conditions" or "Acceptable".
Priority 3 (P3)	These classification areas are defined to manage the risk of pollution to the water source from catchment activities. Protection of P3 areas is mainly achieved through guided or regulated environmental (risk) management for land use activities. P3 areas are declared over land where water supply sources coexist with other land uses such as residential, commercial and light industrial development. Land uses considered to have significant pollution potential are nonetheless opposed or constrained.

* Source: Government of Australia: Department of Environment, 2004.

Table 3.2: Descriptions of Protection Zones

Protection Zones	Description
Wellhead Protection Zones (WHPZ)	These zones are used to protect underground sources of drinking water. They are circular (unless information is available to determine a different shape), with a radius of 500 metres in P1 areas, and 300 metres in P2 and P3 areas. WHPZ do not extend outside PDWSA boundaries.
Reservoir Protection Zones (RPZ)	These zones consist of a statutory 2 kilometre wide buffer area around the top water level of storage reservoirs in the Perth water supply area, and include the reservoir water-body. The RPZ apply over Crown land and prohibit public access to prevent contamination (physical, chemical and biological) of the source water. RPZ do not extend outside PDWSA boundaries.

*Source: Government of Australia: Department of Environment, 2004

The determination of the priority classification areas or protection zones over land in a PDWSA is based on:

- the strategic importance of the land or water source;
- the local planning scheme zoning;
- the form of land tenure; and
- the existing approved land uses and activities.

It is of interest to note that a land use is only deemed 'acceptable' if it is not likely to harm drinking water. An unacceptable land use is labeled as 'incompatible'. Otherwise, mitigation measures such as best management practices may be needed in order for a land use to be categorized as 'compatible with conditions'. See Table 3.3 for a further description of how these categories of compatibility are delineated.

Table 3.3: Discriminating Factors Used to Determine the Compatibility of Land Uses in Public Drinking Water Source Areas

Level of Compatibility	**Description**
Acceptable	Means the land use is accepted by DoE as not likely to harm the drinking water source, and is consistent with the management of objectives of that priority classification. The adoption of best practice environmental management methods for new proposals to protect water quality is expected.
Compatible With Conditions	Means the land use is likely to be accepted by DoE as not likely to harm the drinking water source, (and is consistent with the management objectives of the priority classification) provided best environmental management practices are used. This may result in the application of 'specific conditions' (via the planning or environmental approval processes) that must be complied with to ensure the water quality objective of the priority area is maintained.
Incompatible	Means the land use is UNACCEPTABLE[6] to DOE as it does not meet the management objectives of the priority classification area (there is not a list of unacceptable uses). DOE will normally oppose approval of these land uses through the planning decision making process and under legislation administered by DOE. If planning decisions are made to approve these land uses (e.g. as a consequence of a planning appeals process) then DOE should be advised of that decision and have been directly involved in providing advice to the planning decision makers on water quality protection issues.

* Source: Government of Australia: Department of Environment, 2004.

Therefore, a land use will be classified with one of these three labels depending on the Priority Classification Area in which it is found. For example, the Department of Environment for

[6] 'Unacceptable' land uses are not specified by the Government of Australia's *Water Quality Protection Note: Land Use Capability in Public Drinking Water Source Areas*, 2004. These land uses are to be identified by local governments when developing local planning strategies, structure plans and town planning schemes (Government of Western Australia: Department of Environment, 2004).

Western Australia recommended the compatibility for rural[7] uses within a Priority 1 Classification Area to be Incompatible. If this type of land use is located in a Priority 2 or 3 Classification Area, it would be regarded as Compatible with Conditions.

Overall, the Australian Federal, State and Territorial Governments seem to be at an intermediate state of development in regard to source water protection. Within the past ten years, there have been much needed advances in water quality guidelines, strategies, and environmental acts geared towards the protection of drinking water supplies. However, this study found that most of the water quality policies throughout Australia are not legally enforceable and simply voluntary.

3.2 New Zealand

New Zealand has one central government and does not consist of a federation of states. Consequently, the central government in New Zealand is responsible for drinking water quality. It is stated by the New Zealand Ministry of the Environment in the Background Paper on Proposed National Standards for Raw Drinking Water Sources that New Zealand has some of the best drinking water quality in the world. This is largely due to the lack of industry within this relatively small[8] country. Despite this fact, New Zealand does have problems with nutrient and microbiological contaminants. It has one of the highest rates of gastroenteritis[9] in the world caused by *Campylobacter*, *Cryptosporidium*, and *Giardia*. Given the inherent susceptibility of New Zealand water resources to contamination, water quality standards and risk prevention measures are vital for the protection of public health throughout the nation.

In 1956, the New Zealand Ministry of Health created the *Health Act*. This Act, including numerous amendments to follow, came into law as the primary legislative work governing drinking water and public health. This Act does not contain water quality standards or directly address the protection of source waters. In 1995, the *Drinking Water Standards for New Zealand* were developed and further amended in 2000. These standards are based on the World Health Organization (WHO) Guidelines for Drinking-Water Quality (1998) and were created for the intention of:

[7] Rural uses includes farm supply centres, manure stockpiling/ processing facilities.
[8] New Zealand has a total land mass of 270,000 sq km.
[9] Gastroenteritis is a disease also known as 'stomach flu' or 'winter vomiting disease' which is diagnosed by nausea, vomiting, abdominal cramps, and diarrhea (Walker, T.S. 1998)

- setting out of the requirements for compliance with the standards,
- facilitating the consistency of application throughout New Zealand,
- protecting public health while minimizing unnecessary monitoring, and
- being appropriate for both large and small drinking water supplies.

It is important to emphasize that these standards are only applicable to water intended for drinking, irrespective of its source (New Zealand Ministry of Health, 2000). Further, as stated by the Ministry of Health for New Zealand, compliance with these standards is not mandatory in New Zealand (New Zealand Ministry of Health, 2001). Yet, this document recognized microbiological contaminants as the top priority with respect to health risks. These standards also introduce the concept of 'Maximum Acceptable Value (MAV)' which represents the concentration of a determinand[10] below which the presence of the determinand does not result in any significant risk to a consumer over a lifetime[11] of consumption. This definition thus implies that if the concentration of a contaminant is above the MAV, it is considered a significant risk to public health. This concept could also be a potential method for determining a significant direct threat to source water.

In June of 2004, the Ministry for the Environment released a report to propose a standard for raw drinking-water sources in order to complement the Ministry of Health legislation and standards for improving drinking water supply and delivery. This document entitled, Background Paper: Proposed National Environmental Standard for Raw Drinking-Water Sources infers a comprehensive source-to-tap approach to the management of drinking water. This multi-barrier[12] approach will require monitoring, grading, and reporting the suitability of raw drinking-water sources (New Zealand Ministry for the Environment, 2004).

There are two types of grades incorporated into to the framework used for assessing the suitability of water sources;

- An underlying grade, which is a grade for each identified contaminant; and
- An overall grade, which characterizes the suitability of the raw source from the underlying contaminant grades.

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[10] A determinand is a constituent or property of the water which is determined in a sample. An example of a microbial determinand is the total coliform count (New Zealand Ministry of Health, 2005).

[11] Lifetime consumption is based on a person drinking 2L of water a day for 70 years.

[12] Multi-barrier is defined as an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking-water from source to tap in order to reduce risks to public health (New Zealand Ministry for the Environment, 2004).

There are three steps involved in this process for grading a drinking-water source. These steps are as follows:

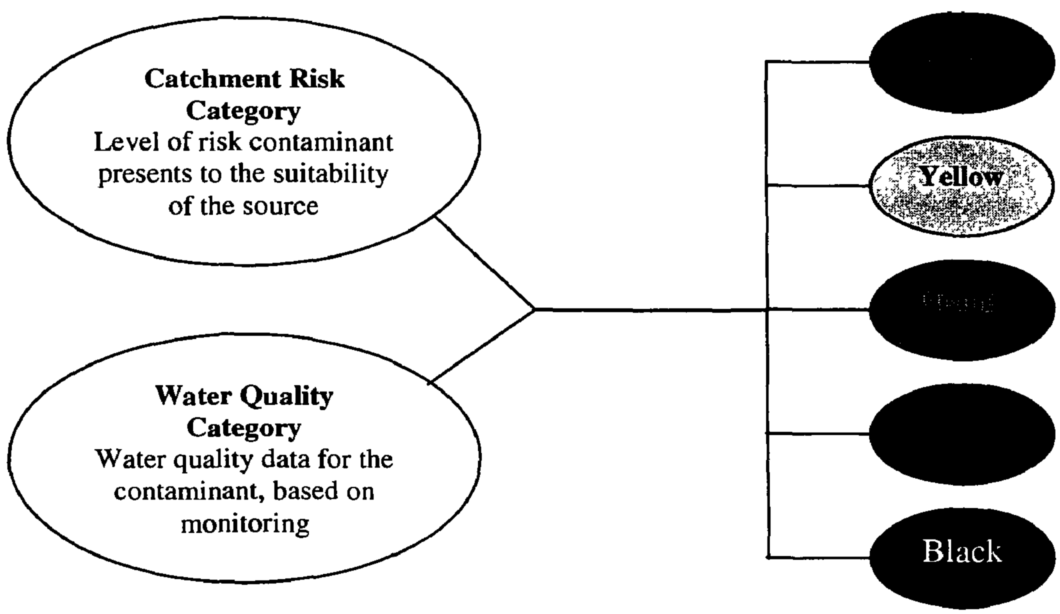
Step 1: Establish Grades for Each Contaminant

Step 2: Establish Contaminant Class Grades

Step 3: Establish the Overall Grade

The following diagram (Figure 3.1) shows the first step of this process.

Figure 3.1: Grading Scheme for Individual Microbial Contaminants



* Source: New Zealand Ministry for the Environment, 2004, p.13.

Once each contaminant has been given an individual grade, step two involves placing all individual contaminants into one of the following five categories:

- o Chemical Contaminants (Aesthetic)
- o Chemical Contaminants (Health Significant)
- o Particles
- o Microbes
- o Toxins

The contaminant class grade is set equal to the worst grade for a contaminant within the class. It is important to note that this proposed National Environmental Standard for Raw Drinking-Water

Sources does not set a specific level at which the activity producing the contaminant is unacceptable. For microbiological contaminants, the MAVs are too low to be used for categorizing source water areas. Instead, the degree of treatment required to produce safe raw water is used as the basis for defining the microbial water quality categories. The overall grade is then determined by the lowest contaminant class group grade of Chemicals, Microbes, and Toxins. See Table 3.4 for overall class grade descriptions. The same colour scale and suitability meaning is used as for the individual contaminant grades.

Table 3.4: Description and Interpretation of Each Overall Grade

Grade	Suitability Description	Interpretation
Green	Very Good Suitability	No treatment is required to make water safe for drinking.
Yellow	Good Suitability	Reliance on treatment to remove low levels of microbes to make the water safe; or chemicals or cyanobacteria present but no treatment required.
Orange	Fair Suitability	Reliance on treatment to remove moderate levels of microbes to make the water safe.
Red	Poor Suitability	Reliance on treatment to remove high levels of microbes, or chemicals or toxins, to make the water safe
Black	Very Poor Suitability	Heavy reliance on treatment to remove high levels of chemicals, toxins or microbes

* Source: New Zealand Ministry for the Environment, 2004, p.15.

This strategy for assessing raw water quality suitability is important because it provides an example of one method which may be utilized for assessing the level of risk associated with a specific source watershed. This may be incorporated into a more complex process for determining a significant direct threat to source water.

A retrospective look at the New Zealand legislation shows a lack of legally binding legislation geared towards the protection of source water and it fails to define significant direct threats. Yet, the use of Maximum Acceptable Values for drinking water standards and the proposed source water suitability assessment process are interesting concepts which could be used to define significant direct threats of pathogens to source watersheds.

3.3 Europe

The European Union (EU), composed of 25 independent states, was established by the Treaty of Rome in 1957 to enhance political, economic and social growth. Currently, there are four major governmental institutions which make up the EU. The primary legislative body which can implement regulation and directives is the European Commission (EC). In 1975, as environmental protection was gaining concern worldwide, the Commission drafted a report on drinking water consumption. This document was later adopted as *Directive 80/77/ECC* in 1980, and was then superseded by *Council Directive 98/83/EC* on the quality of water for human consumption in 1998. In this Directive 'water intended for human consumption' is defined as all water in its original state or after treatment (European Commission, 1998). Yet, in the case of water supplied from a distribution network, the point of compliance is dictated as "at the point…at which it emerges from the taps that are normally used for human consumption" (European Commission, 1998, Article 6 (1a)). This Directive does not establish levels at which microbiological contaminant threats are significant. However, it does set out Maximum Admissible Concentrations (MAC) for pathogens, specifically *E.coli* (zero organisms per 100ml) and E*nterococci* (zero organisms per 100 ml). Member states are required to meet these minimum standards set by this document.

In October 2000, the *EU Water Framework Directive (2000/60/EC)* was adopted for the protection of inland surface waters, transitional waters, coastal waters and groundwater. Under this Directive, Member States must:

- Identify all river basins[13] lying within their national territory.
- Complete an analysis of the characteristics of each river basin district, a review of the impact of human activity on the water, an economic analysis of water use and a register of areas requiring special protection.
- Produce a management plan and programme of measures for each river basin district.

Although the objectives of the river basin management plans are to prevent deterioration, enhance and restore bodies of surface and groundwater, the assessment of microbiological risks is not required and pathogens are not even addressed. The lack of legislation by the European

[13] A River Basin is defined as the area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta (European Commission, 2000).

Commission sends a clear message that the responsibility of source water protection lies in the hands of Member States (European countries) themselves.

3.4 The United Kingdom

The United Kingdom consists of Great Britain (England, Wales and Scotland) and Northern Ireland. Though these nations are ruled by the same Sovereign Queen and Parliamentary System, legislative and regulatory responsibilities are held under the control of each individual country. The following paragraphs summarize the key acts and regulations established in these countries.

3.4.1 England and Wales

The regulatory system for water services in Wales and England is enforced by two agencies: (1) The Office of Water Services, the economic regulator of the water industry, and (2) The Drinking Water Inspectorate, the water quality regulator. The current standards for water quality are found in *The Water Supply (Water Quality) Regulations (Water, Wales and England) 2000.* It is required by this document that "water does not contain any microorganism (other than a parameter)...at a concentration or value which would constitute a potential danger to human health" (The UK Environment Agency, 2000, 4.2 (a,ii)). The microbiological parameters revealed in this regulation are similar to the European Commission Directive (98/83/EC) and require zero *E.coli* and *Enterococci* organisms per 100ml of water. However, exceeding this value is not established by this regulation to correspond to a significant direct threat. Once again, compliance with these parameters is only compulsory at the water treatment facility and at the consumers' tap, but does not apply to the drinking water source. This document also shows concern about *Cryptosporidium* and states that "the Secretary of State may at any time by notice in writing require a water undertaker to carry out a risk assessment by a date specified in the notice to establish whether there is a significant risk from cryptosporidium" (The UK Environment Agency, 2000, Section 28.4 (a)). Further, Section 28.2 (a) of this regulation details that the risk assessment report should set out the results of the assessment, indicating whether there is a significant risk from *Cryptosporidium*. Section 25 further explains that a 'significant risk from *Cryptosporidium*', in relation to water supplied from a treatment works, means a significant risk that the average number of *Cryptosporidium* oocysts per 10 litres of water supplied from the works ... would at any time be one or more. The only reference made to source water, or raw water, is made in Section 26(1) depicting that water shall not be supplied from any source which consists of or includes raw water unless the water has been disinfected.

3.4.2 Northern Ireland

In 2002, Northern Ireland adopted the *Water Supply (Water Quality) Regulations* as set out by the *United Kingdom Water Supply (Water Quality) Regulations of 2000.* The only other document compiled for the protection of source water was released by the Northern Ireland Environment and Heritage Service (EHS) in July 2001. This report entitled Policy and Practice for the Protection of Groundwater in Northern Ireland was created to outline the approach which will be taken by the EHS for the protection of groundwater resources and quality in Northern Ireland. This report describes four main components which should be included in the groundwater protection policy. These components include:

- land zoning according to the classification of groundwater vulnerability to pollution;
- source protection by means of groundwater protection zones;
- specific policy statements on the control of groundwater quantity and quality; and
- monitoring, databasing and analysis.

This report acknowledges the need to consider threats to groundwater quality and quantity in land use planning policies and procedures. Yet, specific microbial risks to groundwater are not discussed in this report. However, as a means of mitigating potentially polluting activities within source catchment areas, this document suggests the designation of special protection areas, called 'Source Protection Zones' in which possible polluting activities are either controlled or restricted. Using this approach, the recharge[14] capture areas of source catchments are divided into three Source Protection Zones:

- Zone I: Inner Source Protection Zone

  Designed to protect against the effects of human activities which might have an immediate effect upon the source, particularly against microbial pollution. It is defined

[14] Recharge is defined as water which percolates downward from the surface into groundwater (Northern Ireland Environment and Heritage Service, 2001).

by a 50 day time or travel (TOT)[15] from any point below the water table to the source and a 50 meter radius minimum from the source.

- Zone II: Outer Source Protection Zone

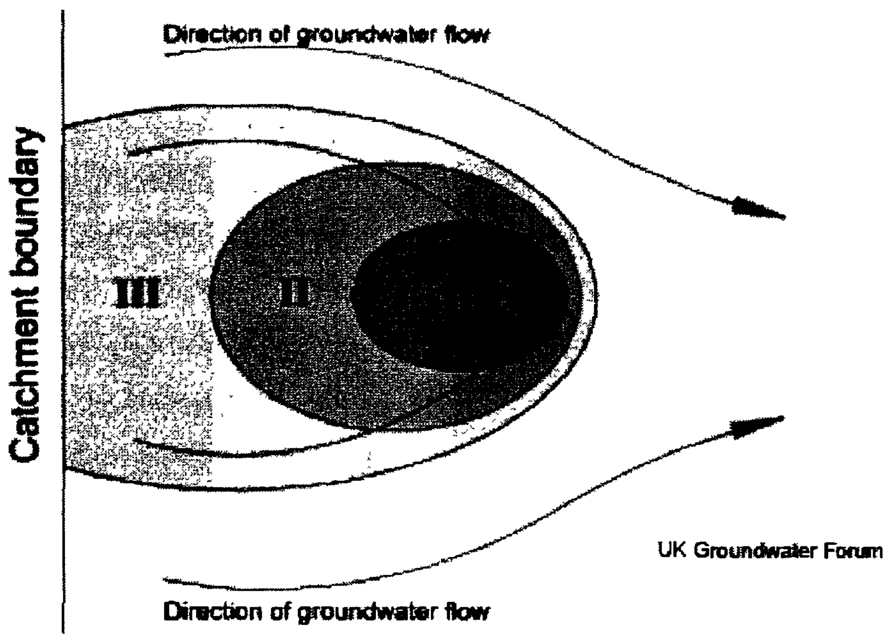
  This zone is larger than the first and is the areas defined by a 400 day TOT from any point below the water table to the source.

- Zone III: Remainder of the Source Catchment

  The shape of this zone can vary in shape and can range from tens to a few thousand hectares. It covers the complete catchment area of a groundwater source and all of the groundwater within it will eventually discharge to the source.

The following diagram (Figure 3.2) illustrates the division of catchment areas into the three Source Protection Zones.

Figure 3.2: Depiction of Source Protection Zones in a Catchment Area



* Source: The Northern Ireland Environment and Heritage Service, 2001, p.15.

Sources for which zones will be produced will be prioritized depending on a number of factors

[15] Time of Travel (TOT) is an estimate of the time required for a particle of water to move in the saturated zone from a specific point to a groundwater source of drinking water (Technical Experts Committee, 2004, p.80).

including water use and size of abstraction. Highest priority will be given to the sources which are used as a Public Water Supply.

Unfortunately, this legislative proposal is not expected to be implemented until 2010.

3.4.3 Scotland

The majority of regulatory standards for drinking water quality in Scotland are derived from European Directives. The original Drinking Water Directive of 1980 (80/777/EEC) was still in force during the year 2000. It was not until the later part of 2003 that Scotland, as well as the rest of the UK, implemented the revised Directive (98/83/EC).

Scottish Water, a publicly owned water supplier answerable to the Scottish Parliament, is required to provide drinking water which is wholesome. *The Water Supply (Water Quality) (Scotland) Regulations (2001)* defines 'wholesome' as water, used for domestic purposes, which does not contain: (i) any microorganism (other than a parameter) or parasite; or (ii) any substance other than a parameter, at a concentration or value which would constitute a potential danger to human health (Scottish Parliament, 2001, s. 4(2a)). This Regulation also dictates the point at which these requirements must be complied, as duly noted in *The Supply (Water Quality) (Water, Wales and England) Regulations 2000*, as (a) in the case of water supplied by a tanker, the point at which the water emerges from the tanker; and (b) in any other case, the consumers' tap (Scottish Parliament, 2001, s. 4(3)). Consequently, the protection of source water resources from pathogen contamination was not a major concern in Scotland at this time.

In 2002, *The Water Industry (Scotland) Act* came into force. Under this legislation, the Drinking Water Quality Regulator for Scotland (DWQR) was declared the new regulating authority responsible for enforcing and ensuring that water suppliers are providing safe water for public consumption. Since the 1980s, *Cryptosporidium parvum* has been identified as the pathogen responsible for numerous outbreaks of Cryptosporidiosis throughout Scotland. In fact, a 2002 report by Binnie Black & Veatch determined that there are over 800 cases of Cryptosporidiosis in Scotland each year (Binnie Black & Veatch, 2002). As a result, *The Cryptosporidium (Scottish Water) Directions* were developed by the DWQR and released in 2002. These Directions were revised further to become the *Cryptosporidium (Scottish Water) Directions 2003*, which came into force in January of 2004. Under this Direction, Scottish Water is obligated to (a) monitor and continue to monitor its raw water sources for the presence of

Cryptosporidium and, having due regard to the catchment risks at individual sites; and (b) ensure that the design and operation of treatment plants is carried out in an efficient and effective way for the purpose of removing *Cryptosporidium* oocysts, taking into account the level of risk at each plant (Drinking Water Regulator for Scotland, 2003, s. 3(1)). This Direction sets out a framework for assessing the risk of *Cryptosporidium* in public water supplies in Scotland and requires Scottish Water to assign a score to each of their supplies depending on the assessed risk. Risk assessments are to be completed for both surface and groundwater sources used as water supplies. The overall risk assessment scores for each water supply are based on a combined Catchment Score and Water Treatment and Supply Score. Table 3.5 shows an example of the grading scheme for Discharges into the Catchment/ Water Source which contributes to the Surface Water Catchment Score.

Table 3.5: Scoring System for Discharges into the Catchment/ Water Source

Score Section	Discharge Source	Score
3.1	Septic tanks serving population of ≤ 100	4
3.2	Septic tanks serving population of > 100	6
3.3	Sewage Works - Population equivalent < 500	4
3.4	Sewage Works - Population equivalent 500 to 5,000	5
3.5	Sewage Works - Population equivalent 5,001 to 20, 000	6
3.6	Sewage Works - Population equivalent 20,001 to 50,000	7
3.7	Sewage Works - Population equivalent > 50,000	8
3.8	Storm Water Outlets	2
3.9	Abattoir/Livestock Market	2

* Source: Drinking Water Regulator for Scotland, 2003 p.18.

The Final Weighted Ground Water or Surface Water Score is then used to classify each water supply as either High Risk (Score >100), Moderate Risk (Score 50-100), or Low Risk (Score <50). Scottish Water is then required to take appropriate action to mitigate the risk of *Cryptosporidium* to the assessed water supply. This Directive also requires continuous monitoring of high-risk supplies for *Cryptosporidium*. The revisions in the 2003 Directions orders more widespread testing for *Cryptosporidium*. It dictates that as of June 2004, every supply in Scotland will be tested at least once a month with the frequency of testing being based on the assessed risk and the flow through the works. *The Cryptosporidium (Scottish Water)*

Directions (2003) is revolutionary for its novel approach to assessing the risks of *Cryptosporidium* to a water supply directly at the source. The identification of significant *Cryptosporidium* sources to water supplies in this document shows that the Scottish government has attempted to determine significant risks to water resources. However, a more comprehensive assessment of significant threats to source watersheds is needed.

3.5 The United States of America

The United States (U.S.) is the third largest country in the world (behind Russia and Canada) and is made up of 50 states and 1 district. There are approximately 161 thousand public water systems throughout the U.S. supplying domestic water to an estimated 293 million[16] people. Due to the exceptionally large population within the U.S., there is a greater reliance on public water supply systems, and hence, an increased risk of water quality contamination. In 1993, there was an outbreak of cryptosporidiosis in Milwaukee, Wisconsin which resulted in the infection of over 400,000 people and killed approximately 80 people (U.S. Environmental Protection Agency, 2003b). This was the largest recorded waterborne disease outbreak in United States history (U.S. Environmental Protection Agency, 2003b), and one of the most catastrophic water contamination incidents that the world has ever seen. Consequently, the United States has a particularly substantial need for water quality protection policies and regulations.

In 1969, the first federal general environmental policy was passed called *The National Environmental Policy Act (NEPA)*. Under this Act, the United States Environmental Protection Agency (USEPA) was created as the independent federal agency responsible for environmental protection. Since then, the USEPA has led the United States in the development and enforcement of regulations that implement environmental laws enacted by the U.S. Congress. As the preliminary national charter for protection of the environment, NEPA required federal agencies to integrate environmental values into their decision making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. In order to comply with this requirement, this Act states:

> "that federal agencies must include in any recommendation or report on proposals for legislation and other major Federal actions *significantly* affecting the quality of the environment, a detailed statement by the responsible official on –

[16] This estimated value was taken from the US Central Intelligence Agency, 2004.

(i) the environmental impact of the proposed action" (U.S. Department of Energy, 1969, s.102(c)).

This presented the first attempt to use the word 'significant' in relation to the environment and was met with a great deal of controversy due to the arbitrary nature of this word.

In 1974, *The Safe Drinking Water Act* was enacted under the U.S. Environmental Protection Agency and replaced *NEPA* as the main federal law governing the quality of U.S. drinking water. Prior to this Act, states had the responsibility for public water supplies, and the programs were found to contain many deficiencies, including inadequate treatment and poor water quality (Moeller, 2001). This Act was further amended in 1986 and 1996 to require increased actions for the protection of drinking water and its sources. The 1996 amendments greatly enhanced the existing laws by acknowledging source water protection, operator training, funding for water system improvements, and public information as vital components of safe drinking water. The revised *Safe Drinking Water Act (1996)* ensures safe drinking water quality from source to tap. In addition, this document gives the USEPA the authority to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water. Subsequently, the USEPA developed the *National Primary Drinking Water Regulations (2002)* which set maximum levels for particular contaminants in drinking water or required ways to treat water to remove contaminants. Further to setting these standards, the USEPA provides guidance, assistance, and public information about drinking water, collects drinking water data, and oversees state drinking water programs. The *National Primary Drinking Water Regulations (2002)* are legally enforceable, therefore, both the USEPA and in some cases the state governments can take enforcement measures against water systems for not meeting safety standards. The microbiological standards, for water at the tap, set out by these Regulations are shown in the following chart (Table 3.6).

Table 3.6: National Primary Drinking Water Regulations - Microbiological Standards

Microorganism	MCLG [17](mg/L)	MCL[18] (mg/L)
Giardia lamblia	zero	99.9% inactivated
Legionella	zero	no data
Total Coliforms (including fecal coliform and *E.coli*)	zero	zero on 95% of the samples taken
Viruses (enteric)	zero	99.9% inactivated

* Source: The USEPA. The Drinking Water Standards: The National Primary Drinking Water Regulations.

The USEPA also released *The National Secondary Drinking Water Regulations.* However, these regulations primarily affect the aesthetic quality of drinking water and do not apply to microbial pathogens.

The USEPA has declared that its source water protection goal is to have "by the year 2005, 60 percent of the population served by community water systems receiving their water from systems with Source Water Protection (SWP) programs in place under both Wellhead Protection and watershed protection programs" (USEPA, 1997). A crucial step in attaining this goal was the development of the federal Source Water Assessment Program (SWAP). The *Safe Drinking Water Act* amendments of 1996 required states to develop and implement Source Water Assessment Programs to analyze existing and potential threats to drinking water quality throughout the state. Under the amendments to this Act, source water assessments are to be completed for each public water system or on an 'area wide basis' involving multiple public water supplies (USEPA, 2002d). Consequently, the USEPA released the State Source Water Assessment and Protection Programs Guidance in August of 1997. This document describes the elements of an EPA-approvable SWAP submittal and provides recommendations for what may be included in a SWP program. There are four elements which comprise state SWAPs. These include:

- Delineating the source water protection area (SWPA), used to determine the portion of a watershed or groundwater area that may contribute water (and, therefore, pollutants) to the water supply.

[17] Maximum Contaminant Level Goal (MCLG) - The maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health effect of persons would occur, and which allows for an adequate margin of safety. MCLGs are non-enforceable public health goals.

[18] Maximum Contaminant Level (MCL) - The maximum permissible level of a contaminant in water which is delivered to any user of a public water system. MCLs are enforceable standards. The margins of safety in MCLGs ensure that exceeding the MCL slightly does not pose significant risk to public health.

- Conducting a contaminant source inventory (to be determined by each state), this involves the identification of all significant potential sources of drinking water contamination within the SWPA. The resulting contamination source inventory must describe the sources (or categories of sources) of contamination either by specific location or by area.
- Determining the susceptibility of the public water supply (PWS) to contamination from the inventoried sources. The susceptibility determination can be either an absolute measure of the potential for contamination of the PWS or a relative comparison between sources within the SWPA.
- Releasing the results of the assessments to the public.

Due to the financial demands of developing Source Water Assessment Programs, the Federal Drinking Water State Revolving Fund was set up and made available to all states to assist with source water assessment and protection activities. State programs were to be submitted to the EPA in February 1999. At present, the EPA has approved 52 SWAP programs. Although these SWAPs are not intended to determine significant direct threats to source water resources, they do identify relative threats to water quality and help water suppliers and communities determine protection priorities for addressing these threats.

The 1996 amendments to the *Safe Drinking Water Act* also required the USEPA to develop regulations that require the disinfection of groundwater as a means of further protecting public health and source water resources. At present, only surface water systems and groundwater systems under the direct influence of surface water are obliged to disinfect their water supplies. This led to the *Proposed Ground Water Rule* which was released on May 10th, 2000. This proposed rule specified the appropriate use of disinfection in groundwater and established multiple barriers to protect against bacteria and viruses in drinking water from groundwater sources. This rule is designed to apply to all public water systems with 15 or more service connections or serving at least 25 individuals a day for 60 days of the year (USEPA, 2000*). The Proposed Ground Water Rule* was supposed to be issued as a final regulation in 2003, however, it still has yet to be finalized and implemented.

In 2002, the USEPA Office of Ground Water and Drinking Water (OGWDW) released <u>Consider the Source: A Pocket Guide to Protecting Your Drinking Water</u> which provides guidance and information on source water protection as a means of heightening public awareness. In this document, the OGWDW outlines 4 barriers to protect our source water from contamination. These barriers include:

1. Risk Prevention – Protects the watershed by keeping contaminants from entering source water.
2. Risk Management – This barrier includes the collection and treatment of water by trained and qualified operators and the development of emergency response plans in case of natural disasters or terrorist attack.
3. Risk Monitoring and Compliance – Monitoring is to be done at the source; at the treatment facility; in the distribution system; and sometimes at the consumer's tap.
4. Individual Action – The involvement of the public is essential for the protection of source water. An informed, supportive and involved public is the basis of drinking water protection (USEPA, 2002a).

In addition to outlining this multi-barrier approach, this guidance paper also highlights regulatory and voluntary resources, tools and management measures available to States, local governments and consumers to assist in the enhancement of existing and future protection programs. The following sections of this chapter look at two of the SWAP programs which have been developed and approved within state jurisdictions.

3.5.1 Florida

Florida has approximately 6,910 public water systems of which 90 percent use groundwater sources for drinking water and 0.26 percent use surface water sources (Florida Department of Environmental Protection, 1999). The Florida Department of Environmental Protection believes that "the Source Water Assessment and Protection (SWAP) program provides an effective mechanism to proactively protect the State's water sources from potential contamination"(Florida Department of Environmental Protection, 1999). Florida's original groundwater protection program has been in place since 1983. This program has seen a great deal of change and advancement over the past 14 years. In 1998, the EPA approved Florida's Wellhead Protection Program under the Wellhead Protection Rule (62-521, F.A.C) which establishes a consistent 500 foot radius setback around the potable[19] water wells. Outer

[19] Potable is a term used to describe water which is useful for drinking (Florida Department of Environmental Protection, 2004)

protection zones are recommended to local authorities using 5-10 year time of travel (TOT) distances when conducting assessments and protection efforts on areas of an aquifer contributing ground water flow to a well. Unlike most other states, the development of wellhead protection programs by local authorities is mandatory. The restrictions of this rule are shown in Appendix 3.2. Virtually all 467 local governments within Florida address wellhead protection. Where appropriate, the Department will rely on existing local wellhead protection plans, including delineations of existing wellhead protection areas and contaminant inventories, to accomplish the goals of the SWAP program (Florida Department of Environmental Protection, 1999). The contaminant inventory will identify contaminants and their sources or locations within the source water assessment area. Contaminants of concern will include: (1) primary and secondary drinking water standards, (2) minimum criteria regulated by the State of Florida, (3) chemicals and parameters listed in the Department booklet, Ground Water Guidance Concentrations, (4) contaminants regulated by Chapter 62-302, Surface Water Quality Standards, F.A.C., and (5) the protozoa, *Cryptosporidium* (Florida Department of Environmental Protection, 1999). In addition, potential contaminant sources will be assessed to determine land use types within the assessment area, which may include urban, agriculture, wetland, barren land, transportation, and utility land uses (Florida Department of Environmental Protection, 1999). The Florida Department of Water Facilities has been working to develop a Watershed Protection Approach which will invoke a 5 year basin management cycle. Source water assessments (SWAP) will be integrated into the first phase of this cycle; The Preliminary Basin Assessment Phase. The second phase of this cycle will involve strategic monitoring for the gathering of data. The third phase comprises data analyses and model development. The development of a basin management action plan encompasses the fourth phase followed by implementation of this plan in the fifth and final phase.

The SWAP program itself is described in Florida's Source Water Submittal to the EPA to include all of the four elements set out in the EPA's State Source Water Assessment and Protection Programs Guidance (1997). When delineating the source water protection area, 500 to 5000 foot setbacks are to be used for groundwater (depending on the system and geology) with a minimum distance of 5 year TOT. Surface water delineating areas will include, at a minimum, all topographic boundaries for each surface water source and consider all surface water contributing to that source. Groundwater input to a surface water intake will also be considered when appropriate.

The majority of these assessments had been completed for the 2003 EPA deadline. However, the implementation of Source Water Protection programs has yet to be observed throughout the state.

3.5.2 New Jersey

In the state of New Jersey, there are roughly 4136 public water systems, which rely on 6099 groundwater wells and 67 surface water intakes. The monitoring of these water supplies is the responsibility of the public water system. The USEPA and the New Jersey Department of Environmental Protection (NJDEP) require mandatory monitoring of the treated water produced by these public water systems. The test results derived from water quality monitoring are evaluated in comparison to the drinking water quality standards, also known as Maximum Contaminant Levels, set by the USEPA *National Primary Drinking Water Regulations* (2002) described in Section 3.6 of this paper. However, due to the recurrence of contaminants in New Jersey's drinking waters in excess of the USEPA drinking water standards, the 1983 amendments to the *New Jersey Safe Drinking Water Act (Assembly Bill 280*) require New Jersey to develop drinking water standards for a list of organic compounds. By law, New Jersey drinking water standards must be equal to or more stringent than federal standards. In 1995, the NJDEP began a statewide evaluation of drinking water quality. The Maximum Contaminant Levels were used as an indicator for the measurement of microbiological, chemical, and radioactive safety in state drinking water. Microbiological (Total Coliform) monitoring carried out across New Jersey in 1997 found that 97% of the community water systems in New Jersey met the microbiological standards throughout the year.

Prior to 1997, all of the water quality standards and policies in New Jersey were concerned with drinking water at the point of use. The 1996 amendments to the federal *Safe Drinking Water Act* was an important milestone for New Jersey and the rest of the United States because it transformed state drinking water policies to include the protection of drinking water at the source. The New Jersey Source Water Assessment Program is designed to integrate other source water programs such as sanitary surveys, monitoring programs, vulnerability assessments, wellhead protection programs, and state watershed initiatives in order to meet federal requirements.

The preliminary stage in carrying out The *New* Jersey Source Water Assessment Program involves identifying current and future threats to the public water supply. These exact threats are not set out in this document, however, pathogens are indicated as likely contaminants to be identified as potential threats in a source water assessment (New Jersey Department of Environmental Protection, 1999). In addition to the contaminants set out in the federal *Safe Drinking Water Act (1996)*, the New Jersey SWAP will also include *Giardia* and *Cryptosporidium* when assessing pathogenic threats to source waters. Groundwater delineations will be conducted based on a 2-year, 5-year and 12-year time of travel (TOT). Surface water delineations will be based on the entire drainage area that flows past the surface water intake area. Additionally, 5-year groundwater flow delineations will be added to account for groundwater contributions to the base flow of surface waters. The susceptibility of a drinking water source will be based on two factors: sensitivity of the water source to contamination from land use activities and the intensity of use of the contaminants within the delineated area. In 2003, the New Jersey Department of Environmental Protection in partnership with the New Jersey Geological Survey released the Guidelines for Delineation of Wellhead Protection Areas in New Jersey. This document was intended to be used by government officials and outside parties as a reference tool when performing delineations for the New Jersey Well Head Protection Plan or Source Water Assessment Program.

This review clearly depicts The United States as the world leader in the development and implementation of Source Water Protection legislation and initiatives. Despite this, the determination of a significant direct threat to source water still remains undefined.

3.5.3 Wisconsin

The state of Wisconsin derives its name from an Ojibwa word meaning 'the gathering place of waters', which reflects the vast number of rivers, streams and lakes found throughout the state (WDNR, 1999). The Bureau of Drinking Water and Groundwater of the Wisconsin Department of Natural Resources (WDNR) is the agency which governs the activities that affect the safety, quality and availability of water in Wisconsin. There are approximately 11,900 drinking water systems using groundwater in this state, giving rise to over 70% of Wisconsin residents using groundwater for domestic purposes (WDNR, 1999). In addition, over 1.5 million residents in Wisconsin rely on 20 surface water systems which encompass over 12,500 square miles of land area across the state (WDNR, 1999).

Within the United States, Wisconsin has become a leader in protecting surface water as well as groundwater from point and non-point sources of contamination. The urgency for source water protection measures was triggered by the *Cryptosporidium* outbreak in 1993, which occurred in Milwaukee, Wisconsin killing 80 people and sickening over 400,000 others (WDNR, 1999). Consequently, the WDNR has implemented two important programs that deal with source water protection; The Wellhead Protection Program and The Source Water Assessment Program. Wisconsin has a long history of groundwater protection which began with Wisconsin's *Groundwater Protection Act* (1984). The Wellhead Protection Program was established following the 1986 amendments to the *Safe Drinking Water Act (1974)* which required all new wells to have wellhead protection programs in place (USEPA, 1986, sec. 300h-7(a)). The goal of this program was to prevent contaminants from entering public water supply wells through the management of land use practices that contribute to the wells. This program was approved by the USEPA in 1993 and included the following requirements for wellhead protection plans:

- A delineation of recharge areas for proposed wells;
- Identification of the zone of influence for the proposed well;
- An inventory of existing potential sources of contamination within a half mile radius of the well and an assessment of existing potential sources of contamination within the recharge areas of the well; and
- A contingency plan for providing safe water in the event of any contamination incident (Wisconsin Department of Natural Resources, 1993).

Although pathogens are not specifically identified as significant threats to groundwater wells, storm and sanitary sewers, septic systems, sludge and wastewater spreading, livestock waste storage and spreading, and infiltration lagoons were listed as potential contaminant sources (WDNR, 1993).

The cornerstone for surface and groundwater protection in the United States was marked by the passing of the *Safe Drinking Water Act* in 1974. As discussed previously in Sections 3.5.1 and 3.5.2, this Act required all states to develop and implement source water assessment programs (SWAPs) for all surface and groundwater sources of drinking water. In response, the

WDNR produced its own source water assessment program plan, and following public review, submitted it to the USEPA in October of 1999 and was approved in November that same year. Wisconsin's Source Water Assessment Program Plan is designed to provide a description of the assessment process, a map of the source water areas, an identification of significant potential contaminant sources, and a determination of susceptibility for each public drinking water system (WDNR, 1999). Further, contaminants of concern include those which are regulated under the *Safe Drinking Water Act* (1974). The time of travel (TOT) for pathogens allocated to source water areas is to be 14 months or synonymous with the TOT outlined in the USEPAs *Groundwate Rule* (WDNR, 1999). In addition, prior to the introduction of the Wisconsin SWAP, several programs had already been implemented for the protection of surface waters including:

- Outstanding Resource Classification / Exceptional Resource Classification and Anti-degradation Program;
- Water quality standards and effluent limit calculation loads;
- Wisconsin non-point source / priority watershed program and redesigned priority project program;
- Integrated Watershed Planning Activities; and
- Shoreline / Waters Initiative (WDNR, 1999).

All of these programs are to be integrated into the Wisconsin SWAP.

Another watershed management technique adopted by the WDNR is the idea of Total Maximum Daily Loads (TMDLs). This concept, as developed by the USEPA under the *Clean Water Act* (1972) is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources (USEPA, 2005d). The identified amount of pollutant that the water can tolerate is allocated between point sources and non-point sources and must be approved by the USEPA. While TMDLs have been required by the *Clean Water Act* since 1972, until recently, not many have been developed across the country. In an effort to speed up the Nation's progress toward achieving water quality standards and improving the TDML program, the EPA issued regulation in 1985 and 1992 that implement section 303(d) of the *Clean Water Act* – the TMDL provisions. The state of Wisconsin has established TMDLs for several different pollutants, including sediments and phosphorous, which threaten source watersheds throughout the state. However, TMDLs have not yet been determined for any pathogens present in source waters (WDNR, 2005).

3.6 Canada

In Canada, boil water advisories are issued to alert citizens when the water supplying a certain location is unsafe for consumption. These warnings are made public when there is evidence of unacceptable microbiological quality, unacceptable turbidity, equipment malfunction during treatment or distribution, inadequate disinfection during treatment, and/ or significantly diminished source water quality (Health Canada, 2001). Incidents of adverse water quality affect communities in all provinces across Canada. Between 2000 and 2004, there were 347 boil water advisories in Ontario alone. For this reason, coupled with continuous beach closures[20] and recent waterborne disease outbreaks in Saskatchewan and Ontario, Canadian citizens have become increasingly aware of the precious value of their freshwater resources and the need to protect sources of drinking water.

Within Canada, all levels of government have direct or indirect responsibility for drinking water. However, the legislative authority for natural resources, as set out by *The Constitution Act of 1867,* is allocated to the provinces and territories, whereas oceans, fisheries, and water on federal lands lie under federal jurisdiction. As of 2001, the provinces of Alberta and Quebec had not yet developed legislation for source water protection. However, these provinces had established statutory laws protecting drinking water quality. At this time, these were the only provinces to implement mandatory drinking water guidelines, while the other provinces simply adopted them as objectives. By 2003, as stated in Health Canada's Public Health Initiatives Related to Drinking Water Quality in Canada, each province and territory had adopted legislation to protect its source waters and to establish requirements to provide clean safe and reliable drinking water to its citizens. The authorities responsible for drinking water in British Columbia, Manitoba, New Brunswick and the territories are the health ministries. In all other provinces, this responsibility presently rests with the ministries of environment.

As a department of the Canadian Federal Government, Environment Canada plays a lead role with respect to source water protection including monitoring, freshwater research, risk

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[20] In Ontario, beaches are closed when bacterial *(E.coli)* levels exceed 100 organisms / 100 mL (Lake Ontario Waterkeeper, 2004).

management, emergency response and policy support. The *Canadian Environmental Protection Act, 1999* was the first federal legislation to legally enforce the protection of the environment. This Act defines the environment as:

> "The components of the Earth and includes
> (a) air, land and water
> (b) all layers of the atmosphere
> (c) all organic and inorganic matter and living organisms; and
> (d) the interacting natural system that include components referred to in paragraphs (a) and (c)" (Department of Justice Canada, 1999, c. 33).

Although this was the first *Act* put in place to protect the environment (including water resources), the need for water protection policy had been addressed by the federal government more than 10 years earlier in the *1987 Federal Water Policy* (Environment Canada, 1987). In essence, this policy recognized Canada's freshwater as an undervalued natural resource and a scarce commodity that must be managed efficiently. The goals of this policy are to (1) protect and enhance the quality of the water resource, and (2) promote the wise and efficient management and use of water.

It wasn't until the beginning of the millennium that federal guidelines and policies began to consider the direct protection of drinking water. Over the past 30 years, the federal, provincial, and territorial governments have collaborated to protect drinking water through the Federal-Provincial-Territorial (F/P/T) Committee on Drinking Water. In 2001, following the waterborne disease outbreaks in Ontario and Saskatchewan, this committee released a document entitled Guidance for Safe Drinking Water in Canada: From Intake to Tap (F/T/P Subcommittee on Drinking Water, 2001). This guidance document stresses the importance of a multi-barrier approach as the most effective way to ensure that Canada's drinking water is safe and clean. Later in 2002, the same committee, along with the Canadian Council of Ministers of the Environment (CCME), released the document From Source to Tap: The Multi-Barrier Approach to Drinking Water which provides further insight into the concept of a multiple barrier approach to drinking water and outlines the elements of this strategy (F/T/P Committee on Drinking Water and the CCME, 2002). This document was later reformed by the F/P/T Committee on Drinking Water and the CCME in June of 2004 and was given the title From Source to Tap: Guidance on the Multi-Barrier Approach to Safe Drinking Water (F/T/P Committee on Drinking Water and the CCME, 2004a). This new document provides additional guidance to drinking water system owners and operators on how to apply the concept of the multi-barrier approach to Canadian drinking water supplies. Earlier the same year, the F/P/T Committee on Drinking Water and the CCME developed the Guidelines for Canadian Drinking Water Quality. These guidelines set out the basic parameters that every water system should strive to achieve in order to have the cleanest, safest and most reliable drinking water supply possible. This document recognizes that exposure to microbiological organisms through drinking water could lead to adverse health effects. Consequently, these guidelines set the Maximum Acceptable Concentration (MAC) for bacteriological quality of public, semi-public, and private drinking water systems to zero coliforms detectable per 100 ml (F/P/T Committee on Drinking Water and the CCME, 2004b). This document also addresses the threats of Protozoa (*Giardia* and *Cryptosporidium*) and Viruses but does not set numerical guidelines for these types of pathogens.

Table 3.7 shows an extract from Appendix 3.1 summarizing the source water and drinking water legislation implemented in Canada.

Table 3.7: Drinking Water and Source Water Legislation Implemented in Canada

Legislative Documents related to Drinking Water and Source Water Protection	**Key Environmental Authority**	**Does this Document Contain Water Quality Standards?**	**Is Legislation Legally Binding or Voluntary?**	**Are Microbes (Pathogens) Addressed?**	**Is an Acceptable Level of Risk Addressed?***
Guidelines for Canadian Drinking Water Quality, 2004	The F/P/T DWS[1]	Yes	Voluntary	Yes, primarily concerned with E.coli and total coli forms. Does address some protozoa and viruses.	No, but a proposed Maximum Acceptable Concentration value is used for microorganisms.
From Source to Tap: Guidance on the Multi-Barrier Approach to Safe Drinking Water, 2004	CCME[2] and the F/P/T DWS	No, provides detailed information for owners and operators on how to integrate the multi-barrier approach.	Voluntary	Yes	No
From Source to Tap: The Multi-Barrier Approach to Safe Drinking Water, 2002	The F/P/T DWS	No, outlines the elements of the multi-barrier approach.	Voluntary	Yes, recognizes pathogens as a risk to drinking water quality.	No

* The entire summary table is found in Appendix 3.1

Despite these federally-developed guidelines to initiate more stringent management efforts for drinking water and its sources, ultimately, the responsibility of creating source water protection laws and policies remains with the governing provinces and territories. The point of the following reviews are to identify the province's approach (if any) to identifying and legislating significant risks to source water.

3.6.1 British Columbia

Second to Ontario, British Columbia (B.C.) uses more groundwater than any other province in Canada (B.C. Ministry of the Environment, 2003). It also has one of the highest rates of boil water advisories in the country, with 340 adverse water quality alerts, exclusively, in

2003. Between 1980 and 2004, there were a total of 28 waterborne disease outbreaks in this province. *Giardia lamblia* caused the majority of these outbreaks while other pathogen sources of disease included *Cryptosporidium*, *Salmonella*, and *Campylobacter* (Regional District of Nanaimo, 2004).

There are more than 3500 water systems in British Columbia which fall under drinking water legislation governed by the Ministry of Health Services. As of 1996, B.C.'s water distribution and supply systems were, on average, the second oldest in the country and had an average age beyond the lifespan for such systems (British Columbia Ministry of Health Planning and Ministry of Health Services, 2002). Source water management is the responsibility of the Ministry of Water, Land and Air Protection. The first drinking water regulation was introduced in 1992 under the *Health Act*. The primary purpose of this document was to regulate water providers by requiring them to monitor water quality and to warn health officials of potentially unsafe conditions. However, given the continuation of drinking water-related illnesses following this regulation, greater protection efforts needed to be done. In response, B.C.'s Auditor General published his 1999 report on Protecting Drinking-Water Sources (Office of the Auditor General of British Columbia, 1999). In this report, 26 recommendations for the protection of drinking water sources were proposed. Some of the key recommendations included:

- Improving the protection given to drinking-water sources resulting from single-resource management processes such as forestry, cattle grazing, recreation, transportation, agriculture, and septic tank systems. *(This is presumably where high risk sources (threats) would be identified).*
- Building an information base for better management of groundwater, through more extensive mapping of aquifers and monitoring of groundwater quality and quantity.
- Reviewing the responsibilities and needs of small water-system operators.
- Giving better support to water management processes by designating a lead agency for drinking water, by developing better accountability reporting, and by examining the rights of resource access of drinking-water suppliers.

The Auditor General also noted that even with sufficient protection at the source, some forms of water treatment are necessary. He concluded that, "a layered or 'multi-barrier' approach, combining a mix of protection and treatment, offers the best value for money" (Office of the Auditor General of British Columbia, 1999).

Following the recommendations set out by the Auditor General, the province introduced the *Drinking Water Protection Act* in 2001 (Government of British Columbia, 2001). However, regulations were still needed to implement the requirements set out in the *Act.* In February of 2002, a Drinking Water Review Panel was appointed by the provincial government to review the *Act* and make recommendations. After considering the panel's recommendations, the government passed the amended *Drinking Water Protection Regulation* on May 16, 2003 (British Columbia Ministry of the Environment, 2003). This *Act* is accompanied by regulations which together provide new measures governing drinking water from 'source to tap' to better protect the health and safety of British Columbians. This *Act* specifies:

- the need for drinking water advisory committees;
- an increase in the basic expectations for assessing water systems, certifying operators and suppliers, and monitoring and reporting on water quality;
- an increase in power given to drinking-water officers to protect drinking water sources from contamination by any drinking-water health hazard; and
- the obligation of drinking-water officers to oversee a source-to-tap assessment of every drinking water system in the province to address all potential risks to human health.

It is important to note that this *Act* states that "in the case of a prescribed water supply system, the water supplier must (a) monitor its *drinking water source*, the water in its system and the water it provides for the parameters, and at the frequency, established by the regulations and by its operating permit" (Government of British Columbia, 2001, Section 11 (1a)). However, Table 3.8 shows that the regulations are only concerned with the monitoring of drinking water for fecal coliform bacteria and total coliform bacteria in potable water[21]. Therefore, this standard does not apply to source waters, and viruses and protozoa are not addressed as a concern.

[21] Potable is defined by the B.C *Drinking Water Protection Act, 2001* as "water provided by a domestic water system that (A) meets the standards prescribed by regulation, and (b) is safe to drink and fit for domestic purposes without further treatment" (Government of British Columbia, 2001).

Table 3.8: Drinking Water Protection Regulation: Water Quality Standards for Potable Water

Parameter	**Standard**
Fecal coliform bacteria	No detectable fecal coliform bacteria per 100 mL
Escherichia Coli	No detectable *Escherichia Coli* per 100 mL
Total coliform bacteria	
(a) 1 sample in a 30 day period	No detectable total coliform per 100 mL
(b) more than 1 sample in a 30 day period	At least 90% of samples have no detectable total coliform bacteria per 100 ml and no sample has more than 10 total coliform bacteria per 100 ml

* Source: British Columbia Ministry of the Environment, 2003.

The implementation of these key legislative documents and other drinking water initiatives has been part of the Action Plan for Safe Drinking Water in British Columbia (B.C. Ministry of Planning and Ministry of Health Services, 2002). In addition to stronger and more effective legislation and regulation, this action plan strives to:

- Integrate a source-to-tap approach to water protection in B.C.
- Improve leadership and accountability.
- Ensure better co-ordination and co-operation between agencies involved improving drinking water.
- Provide increased and more effective monitoring and assessment of local drinking water systems.
- Recognize the unique challenges involved in operating and maintaining small water systems.
- Provide funding for improved and expanded services in a way that is fair, workable and affordable.

In accordance with this action plan, the *Ground Water Protection Regulation* (GWPR) was enacted in 2004. Prior to the GWPR, there was no regulation in British Columbia focusing specifically on groundwater or standards for well construction, maintenance, well closure and qualifications for well drillers and well pump installers. This is surprising considering that B.C. uses the second greatest amount of groundwater compared with any other provinces in Canada and is second only to Ontario. The purpose of the GWPR is "the protection of the quantity and quality of the province's valuable ground water resource by: (a) setting out standards to safeguard and maintain the integrity and efficient use of the ground water resource, and (b) ensuring potentially threatening activities around well water and groundwater are undertaken in an environmentally safe manner" (Government of British Columbia, 2004). It was developed to be completed in three phases and applies to water supply wells, ground water monitoring wells, recharge and injection wells, drainage wells, remediation wells, and geotechnical wells that do not involve water transfer. All requirements of the GWPR are to be adopted by all well owners by November 1, 2006.

Although B.C. source and drinking water protection measures in the past have been minimal and progressively slow, this province has invested a substantial effort in this area in recent years. Policy developers and source watershed managers in British Columbia have indicated the need to improve source water protection policies and practices in order to combat the associated risks. Yet, there has been no attempt to delineate significant direct threats to source water resources.

3.6.2 Ontario

The majority of Lake Ontario's beaches are unfit for swimming and recreational enjoyment for much of the year due to high levels of *E.coli*, which exceed microbial standards (Lake Ontario Waterkeeper, 2004). As mentioned earlier, Ontario also has a high number of boil water advisories. These events, demonstrating poor water quality, and the drinking water contamination incident of 2000, which occurred in Walkerton, Ontario, catalyzed the need for increased regulation of drinking water supplies in Ontario. Following this outbreak, Justice Dennis O'Connor was appointed to head the Walkerton Inquiry. Justice O'Connor's fifth recommendation states that "where the potential exists for a *significant direct threat* to drinking water sources, municipal official plans and decisions must be consistent with the applicable source protection plan" (O'Connor, Dennis. 2002b, p.19). Unfortunately, O'Connor does not elaborate on how to determine a 'significant direct threat', and is thus left to the legislators.

In the process of implementing the recommendations of the Walkerton Inquiry, the Ontario Government introduced three new pieces of legislation and regulations. These include the *Nutrient Management Act (NMA) (2002), the Safe Drinking Water Act (2002)*, the *Sustainable Water and Sewage Systems Act (2002)*, and the *Drinking Water Systems Regulation (2003)*. The MOE has also proposed a *Drinking Water Source Protection Act* which is expected to become law in 2005. The *Nutrient Management Act* (2002) was created by the province of

Ontario to provide for the management of materials containing nutrients in ways that will enhance the protection of the natural environment and provide a sustainable future for the agricultural community (Ontario Ministry of Agriculture and Food, 2002). Stiefelmeyer (2003) investigated pathogen control capabilities in the *NMA (2002)* and found that although this *Act* was included in Ontario's Strategy for Safe Drinking Water, it would not effectively perform as a pathogen management measure. Therefore, further policies and regulations are needed as part of a multi-barrier approach in order to fully protect Ontario's water resources from pathogen contamination. In Part Two of the Walkerton Inquiry, Justice O'Connor recommended that the Ontario government enact a *Safe Drinking Water Act* to deal with the treatment and distribution of drinking water. The government of Ontario followed through on this recommendation and produced *The Safe Drinking Water Act* (2002) which (1) recognized that the people of Ontario are entitled to expect their drinking water to be safe, and (2) provided for the protection of human health and the prevention of drinking-water health hazards through the control and regulation of drinking-water systems and drinking-water testing (Government of Ontario, 2002a). This Act provides a framework for:

- Licensing and accreditation of drinking water laboratories.
- Drinking water standards, including an Advisory Council on Standards.
- Mandatory training and certification of operators of municipal waterworks.
- A requirement for an owner's license for the operation of municipal waterworks.
- A statutory standard of care for municipalities.
- Specific inspection, compliance and enforcement provisions (Health Canada, 2003).

In 2003, the Advisory Committee on Watershed-based Source Protection Planning released its report – Protecting Ontario's Drinking Water: Towards a Watershed-based Source Protection Planning Framework (Advisory Committee on Watershed-Based Source Protection Planning, 2003). This document sets out 55 recommendations to create a comprehensive framework which includes roles and responsibilities, the planning process, resources, timing and legislation. Shortly after the Advisory Committee submitted its recommendations to the provincial government, The MOE released the White Paper on Watershed-Based Source Water Protection Planning for public review and comment (MOE, 2004). This document, dated February 2004, articulated the provincial government's determination to develop a comprehensive source water protection program in Ontario. This paper was used to enhance public awareness by explaining concepts related to source water protection and watershed management and highlighting how these practices affect Ontarians. It also outlined the recent initiatives and legislative goals of the MOE. As mentioned in the White Paper, a 16-member Technical Experts Committee (TEC) was established to provide advice to the MOE on an Ontario-based source water threat assessment process. The creation of this committee was one of the recommendations of the Advisory Committee on Watershed-Based Source Protection and is responsible for providing science-based advice for:

- categorizing threats to water;
- linking groundwater protection to surface water management;
- the effects of water-takings on the availability and quality of drinking water;
- appropriate risk management tools for various levels of threats; and
- protecting both current and future drinking water sources (Ontario Ministry of the Environment, 2004c).

In November of 2004, TEC submitted Science-based Decision Making for Protecting Ontario's Drinking Water Resources: A Threats Assessment Framework (TEC, 2004). The recommendations relating to the 'threats assessment framework' laid out in this document are intended to be incorporated into the MOE's proposed source protection legislation. The TEC identified risk identification, assessment and management as the three key steps needed in the threats assessment framework. The delineation of wellhead protection areas (WHPAs) is an important part of risk identification and a 25 year TOT is suggested for the outer boundary of these areas. In addition to the TOT delineation, TEC has recommended that a semi-quantitative approach, such as a 'surface to well advection time' (SWAT)[22], be used to evaluate the vertical travel time of the water from the above ground surface to the aquifer (TEC, 2004). The committee also recommended two pathogen management zones around the wellhead that would represent an area where the drinking water source would be considered highly vulnerable to pathogenic contamination. These are also the areas where significant threats to source watersheds are to be governed. These zones include:

- a 100 m pathogen prohibition area immediately surrounding the wellhead,

[22] SWAT (Surface to Well Advection Time) can be used to measure the degree of protection afforded by the soil above the aquifer.

- a 2 year TOT In the case of DNAPLs[23], and
- a 5 year TOT zone to represent the area where DNAPLs would be subject to the most stringent risk management measures for those compounds.

With respect to Intake Protection Zones, the TEC recommended an approach based on a 2 hour minimum response time. This approach involves correlating the 2 hour response time to a zone on the landscape that traces water flow backwards from the intake, 2 hours upstream and overland. For intakes on the Great Lakes, a fixed radius, 1 km protection zone around the intake was recommended, unless localized or historical impacts suggest that a larger zone is required (TEC, 2004).

The identification of threats to drinking water is another intrinsic part of the Risk Identification step determined by the TEC. The committee recognized that there are certain threats that have been known to impact drinking water sources in more than one instance in Ontario and other jurisdictions. The committee came to the agreement that these particular threats should be considered *Threats of Provincial Concern.* See Table 3.9 for the Threats of Provincial Concern list.

Table 3.9: Threats of Provincial Concern

Threats of Provincial Concern
Chemical Risks
o Artificially enhanced conduits to the aquifer
o Liquid Chemical Storage /Use
o Historical Commercial/ Industrial Sites of Concern
o Waste Storage and Disposal Activities
o Road Salt/ De-icing
o Cemeteries
o Non-sustainable water takings
Biological / Pathogenic Risks
o Biosolids and Septage
o Manure
o Sanitary Sewage and Septics
o Water treatment plant discharges
o Direct Stormwater Infiltration

* Source: Technical Experts Committee, 2004.

The committee's intent in identifying these threats was to recommend that in all vulnerable areas, these threats be subject to a mandatory assessment (Technical Experts Committee, 2004).

[23] DNAPLs (Dense Non-Aqueous Phase Liquids) are chemicals, generally solvents, that are heavier than water.

Of particular importance, the Technical Experts Committee recommended that the most serious risks to drinking water sources be deemed 'Significant Risks', and made the first attempt (worldwide) to define a significant risk as:

> "one that has a high likelihood of:
> - Rendering a current or future drinking water source impaired, unusable or unsustainable; or
> - Comprising the effectiveness of a drinking water treatment process, resulting in adverse health effects" (Technical Experts Committee, 2004, p.x).

It has yet to be seen whether or how the recommendations advised by the TEC will be integrated into the upcoming new source protection legislation promised by the Ontario government.

3.7 Cross- Jurisdictional Review of Source Water Protection Legislation: Summary

All jurisdictions throughout the world rely on water as a vital commodity used for public drinking water. The detrimental frequency of countless waterborne disease outbreaks worldwide and the findings of scientific studies have long-established for water managers the potential public health risks associated with identified sources of chemical and biological contaminants. Although these risks have been known for decades, a legislative approach to source water protection is a relatively new concept. It has taken centuries for government agencies and resource managers to acknowledge and enforce the need for stringent policies and regulations governing source water resources as a means of protecting human health. It is also the case, that tolerance for water-borne risk has declined and the demand for greater risk reduction (as in many aspects of health protection) has increased.

In the past, many environmental authorities throughout the world have relied predominantly on treatment for managing drinking water quality. This approach has major limitations, including the shortcomings of sampling and monitoring techniques; inadequate consideration of the range of factors that affect drinking water quality; and the failure to provide an effective response to microbiological pathogens and contaminants without a prescribed numerical guideline value or established method of analysis (Federal-Provincial-Territorial Committee on Drinking Water, 2001). This review has shown that although guidelines and regulations for drinking water have been put into practice by numerous countries for a few decades, those protecting source water resources have only recently become a global priority.

Leading the world, the United States has taken great strides in the area of source water protection. In accordance with the 1986 and 1996 amendments to the US *Safe Drinking Water Act*, all 52 states are presently moving forward to implement assessments of their public water systems as part of the state source water assessment programs (SWAPs) (USEPA, 2005b). These programs are essential for the effective management of source watersheds, which other jurisdictions, such as Canada, Australia, Scotland, New Zealand and Britain have yet to develop. While these countries have all published guidelines and strategies dedicated to a higher degree of source water protection, implementation of legally-binding regulations has been minimal. The establishment of source water protection legislation must be a top priority in order to ensure the safety of environmental and public health.

The quest for a definition of a 'significant direct threat' to source watersheds was particularly disappointing in this jurisdictional review. While lists of threats have been offered in several jurisdictions, their significance, and actions taken to reduce or eliminate their significance are not evident. The sole attempt to determine the meaning of significance was put forth in the document published by the Technical Experts Committee (TEC) of the Ontario Ministry of the Environment. However, this definition is only a suggestion made by the Technical Experts Committee in hopes that it will be incorporated into the upcoming *Drinking Water Source Protection Act* which is expected to become law sometime in 2005. It will be of interest to see whether this definition becomes part of Ontario legislation.

Chapter Four: Pathogenic Threats to Water Quality

4.0 Pathogens of Greatest Risk to Public Health

In 1996, the World Health Organization stated that the single largest source of human mortality in the world is attributed to infectious diseases (WHO, 1996). Pathogens are the microorganisms responsible for such diseases and are of greatest threat to public health when they are found in water, creating the potential for drinking water contamination. Fawell and Nieuwenhuijsen (2003) pointed out that no drinking water is sterile, consequently, enteric pathogens can be found in the water distribution system and at the tap. Waterborne infection is endemic in developing countries and continues to afflict developing countries despite ongoing advances in drinking water treatment technologies. Todd and Chapman (1974-1996) monitored waterborne disease outbreaks in Canada between 1974 and 1996 and found that in 1996 alone, over 200 outbreaks of infectious disease associated with drinking water were reported to Health Canada. There are several known pathogens that have the ability to give rise to detectable waterborne diseases; however, in North America some are more prevalent than others. This paper will look specifically at four species of pathogens which continuously threaten the quality of water sources across Canada and the United States. These pathogens of particular interest include *E.coli* O157:H7 and *Salmonella*, which are bacterial pathogens; and the protozoan pathogens, *Giardia lamblia* and *Cryptosporidium parvum*. The following review is intended to highlight the survival and transport characteristics of these four principal pathogens in order to determine the level of impact each may impose on water resources and human health, and the effect of these findings on determining the significance of pathogenic risks to source waters. The results of this investigation have been consolidated in Appendix 4.1.

4.1 *Escherichia coli (E.coli)* O157:H7

E.coli is a facultative anaerobe and is part of the normal gut flora found in animals and humans. *E.coli* organisms are largely found in the intestine of healthy humans and animals and are spread by fecal contamination. Most strains of *E.coli* are harmless, rendering less than 1% found in feces, soil and water potentially harmful. However, the majority of harmful *E.coli* strains can cause opportunistic infections of the kidney, bladder, wounds, lungs, or meninges, and each may lead to life threatening sepsis[24]. There are five different strains of *E.coli* including:

- Enterotoxogenic E.coli (ETEC)
- Enteropathogenic E.coli (EPEC)
- Enteroinvasive E.coli (EIEC)
- Enterohemorrhagic E.coli (EHEC)
- Enteroaggregative E.coli (EAEC)

E.coli O157:H7 is an Enterohemorrhagic E.coli (EHEC) for which cattle serve as the primary reservoir, although other animals such as sheep, pigs, poultry and deer may also be inhabited by this organism. *E.coli O157:H7* differs from other *E.coli* strains due to the toxin-producing genes that it carries which have the ability to cause disease. Olson (2001) stated that although the major cause of *E.coli O157:H7* infection is fecal-contaminated meat, fecal contamination of water and soil can lead to waterborne outbreaks of *E.coli O157:H7* infection. This pathogen has an ID_{50}[25] of 10 to 100 organisms. Most people with *E.coli O157:H7* infections recover without antibiotics within 5 to 10 days. However, *E.coli O157:H7* infections in young children and the elderly may lead to hemorrhagic colitis[26] or thrombotic thrombocytopenic purpura (TTP). Patients with hemorrhagic colitis have an 11% chance of developing hemolytic-uremic syndrome (HUS)[27] and 2-7% of these cases are fatal (Olson, 2001). The onset of TTP as a complication of *E.coli* O157:H7 infection can cause neurological damage, seizures, stroke or coma and has a mortality rate as high as 50%.

Research has shown that bacteria, especially *E.coli O157:H7*, can adapt readily to varying environmental conditions. It has been found that this organism can mutate to form a new cell with selected traits that enable it to adapt to the environment in which it lives (Stiefelmeyer, 2003; Robertson and Edberg, 1997). Stiefelmeyer (2003) found that it is common for this bacterium to reach water supplies either through adsorption onto soil particles and carried by runoff, or by leaching through the soil matrix to reach groundwater. Research has also shown that *E.coli* can survive in a viable, but non-culturable state, in municipal, reservoir and lake water

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[24] Sepsis is a systemic disease which occurs when large numbers of bacteria and their byproducts circulate in the blood and can result in death of up to 50% of affected patients (Walker, 1998, p.19).
[25] ID_{50} is the number of organisms (dose) that causes infection in 50% of the subjects
[26] Hemorrhagic Colitis is characterized by copious bloody diarrhea caused by *E.coli* (Walker, 1998, p.158)
[27] Hemolytic Uremic Syndrome is a serious complication of *E.coli* O157:H7 infection whereby red blood cells are destroyed and the kidneys fail to function (Olson, 2001).

for greater than 91 days, 81 days, and 67 days, respectively, all at 25°C (Wang and Doyle, 1998).

The optimum temperature for the survival and proliferation of *E.coli O157:H7* is about 37°C (Ferrer et al, 2003). However, there have been several studies indicating that the ideal temperature for this bacterium varies depending on the environmental medium in which it dwells. Olson (2001) studied the survival of various organisms under different conditions, shown in Table 4.1, and found that *E.coli O157:H7*, living in water, can survive for more than 300 days at a temperature of ≤ 5°C. However, at 30°C, survival is limited to 84 days. The survival duration of *E.coli O157:H7* in a soil environment was also observed to decrease with increasing temperature. The overall length of survival for *E.coli O157:H7* in cattle manure was significantly less than the duration time in water and soil environments. However, the same decreasing survivability was observed with increasing temperature. It was also clearly demonstrated by Olson (2001) that the presence of *E.coli O157:H7* in slurry[28], compost or dry surfaces significantly reduces pathogen concentration.

Table 4.1: Survival of Animal Fecal Pathogens in the Environment

Material	Temperature	*E.coli O157:H7*	*Salmonella*	*G. lamblia*	*C.parvum*
Water	Frozen	> 300 days	> 6 months	< 1 day	> 1 yr
	Cold (5C)	> 300 days	> 6 months	11 wks	> 1 yr
	Warm (30C)	84 days	> 6 months	2 wks	10 wks
Soil	Frozen	>300 days	> 12 wks	< 1 day	> 1 yr
	Cold (5C)	100 days	12-28 wks	7 wks	8 wks
	Warm (30C)	2 days	4 wks	2 wks	4 wks
Cattle Feces	Frozen	>100 days	> 6 months	< 1 day	> 1 yr
	Cold (5C)	>100 days	12-28 wks	1 wk	8 wks
	Warm (30C)	10 days	4 weeks	1 wk	4 wks
Slurry	NA	10-100 days	13-75 days	1 yr	10-100 days
Compost	NA	7 days	7-14 days	2 wks	7 days
Dry Surfaces	NA	1 day	1-4 days	1 day	1 day

* Source: Olson, 2001.

The severe toxicity and durable survival abilities of bacteria, including *E.coli*, indicate that these microorganisms can remain viable over long distances and through various environmental conditions. These characteristics, in addition to the low infective dose of *E.coli*

[28] A slurry is semi-solid manure with just enough dilution water added to allow it to be pumped by a high-solids manure pump (Field and Embleton, 2005). Manure slurry contains a mixture of feces and urine.

O157:H7, demonstrate the serious threat posed by this pathogen to human health. Although chlorination of drinking water will inactivate this strain of E.coli, further precautionary measures are needed to ensure that this organism does not endanger drinking water supplies.

4.2 *Salmonella*

Salmonella is a bacterium that has been known for years to cause a severe infection in humans known as Salmonellosis. This pathogen is often transmitted to humans by consuming water contaminated with infected animal or human feces. Water sources may be contaminated by sewage spills, animals defecating in water or through agricultural runoff resulting from heavy rains. Swine and poultry manure are the main sources of *Salmonella* in the agricultural sector, with the occasional prevalence of this organism in cattle manure (Goss et al., 2001; Stiefelmeyer, 2003). When hosts experience various stresses, such as transportation, crowding, and mixing, they become active carriers of the disease and begin to shed the organisms (Clinton et al., 1979; Olson, 2001; Stiefelmeyer, 2003). The infective dose for *Salmonella* is much higher than *E.coli* at approximately $10^6 - 10^7$ organisms and depends on the age and health of the host, as well as the specific strain of the bacteria. This elevated ID_{50} is due, in part, to the high sensitivity of *Salmonella* to stomach acid. Approximately 40,000 cases of Salmonellosis are reported in North America each year (Olson, 2001). This disease is distinguished by three major symptoms including septicaemia[29], acute enteritis[30], and chronic enteritis. Salmonellosis can last for less than a week and most individuals recover without treatment. However, some patients may develop severe diarrhea requiring hospitalization and the infection can occasionally spread to the blood stream and become life-threatening. In Canada and the USA, 2.5% of people infected with Salmonellosis die each year (Olson, 2001).

Smith (2005) estimated that there are over 2,300 serotypes of bacteria in the *Salmonella* family, but only two types, *Salmonella enteritidis* and *Salmonella typhi*, account for the majority of human Salmonella infections. The *S. typhi* strain is largely responsible for Enteric (Typhoid) fever and is always acquired from a human source, such as feces or urine. On average, 400 cases of Typhoid are reported in the USA every year (Walker, 1998). The onset of Typhoid Fever can occur 7-14 days following the ingestion of *Salmonella*. Symptoms of this disease include

[29] Septicaemia is a potentially life-threatening infection where large amounts of bacteria are present in the blood.
[30] Enteritis is inflammation of the intestine causing symptoms such as diarrhea and abdominal pain.

anorexia, lethargy, headache, an unproductive cough, abdominal pain and a high fever that can reach 40°C. If the infection continues to persist, by the second or third week, the patient may become seriously ill leading to kidney infection, meningitis, empyema[31], infection of the bones, or heart disease (Walker, 1998). The mortality rate of patients inflicted with typhoid fever is 2-10%. Although recovery from this disease is often prolonged (lasting a month or longer), it confers lifelong immunity against typhoid.

The *S. enteritidis* serotype is the *Salmonella* strain responsible for 50,000 cases of *Salmonella* enteritis reported each year in the USA. Water contaminated with animal (mainly chicken) feces is a common source of Salmonella enteritis (Walker, 1998). This disease is characterized by the development of nausea, vomiting, abdominal pain, and diarrhea 8-10 hours following the ingestion of contaminated food or water. This illness is usually self-limiting, but may be life-threatening to infants and the elderly with severe loss of fluids and electrolytes.

Stiefelmeyer (2003) found that when *Salmonella* are excreted into the environment, they can survive for a substantial period of time. As mentioned in Section 4.1.1 and tabulated in Table 4.1, Olson (2001) studied the survival of various pathogens in manure, soil and water. This research demonstrated that *Salmonella* microorganisms thrive best at cold (approximately 5°C) temperatures in soil or feces. Increases in temperature, aeration of slurries, and composting of manure all accelerate the inactivation of *Salmonella*. Conversely, this organism can survive in water for months and cold water acts to prolong the viability. Olson (2001) also found that *Salmonella* is not inactivated by freezing and is relatively resistant to drying. Stiefelmeyer (2003) conveyed in her work that if *Salmonella* is able to disseminate into groundwater resources, it would have the ability to survive for 15 days. Given the survival and virulence characteristics of this bacterial pathogen, it undoubtedly poses a significant threat to the quality of source water if it is not managed appropriately at its source.

4.3 *Giardia lamblia*

The protozoan known as *Giardia lamblia* is a lumen-dwelling flagellate and is a common cause of diarrhea in humans and domestic animals. This organism has a simple, but advantageous life cycle that is crucial to its pathogenicity. *G. lamblia* can exist in the form of

[31] Empyema is a collection of pus in the space between the inner and outer lining of the lung (Blaivas, 2005).

either a flagellated trophozoite[32] or a semidormant cyst. In the cyst stage, this microorganism is resistant to environmental conditions and has about 20% of the metabolic activity used by trophozoites (Walker, 1998). Most importantly, the cyst stage is the infective form of the organism and is resistant to chlorination. Humans are infected when the cysts of *G. lamblia* are ingested and as little as a single cyst can be infectious (Walker, 1998). Giardiasis, also known as 'Beaver Fever'[33], is the most widespread disease caused by *G.lamblia* and is most prevalent where sanitation is poor. This organism is mostly transferred from human to human through contaminated surface water, although animals also have the ability to pass this pathogen to humans. Research has shown that humans, domestic animals, livestock and wildlife can all serve as main hosts for this pathogen (Olson, 2001), while the major reservoirs for *Giardia* cysts on farms are animals younger than six months (Stiefelmeyer, 2003). It is also important to note that research conducted by Olson et al. (1996) concluded that good management practices do not always guarantee a herd's freedom from *Giardia* infection. The results from 20 farms in British Columbia, operating under good management practices, indicated the presence of *Giardia* at all 20 farms, with an overall prevalence of 73%.

Millions of cysts per gram of feces are passed by infected animals and humans, consequently a minimal amount of *G. lamblia* carriers are capable of contaminating waterways (Olson et al, 1999; Stiefelmeyer, 2003). Patients infected with *G.lamblia* may experience acute disease, chronic recurrent diarrhea or no symptoms at all. People afflicted with acute giardiasis will develop nausea and some gastrointestinal uneasiness 9-15 days after the consumption of *Giardia* cysts. This phase usually lasts only 3-4 days and most patients recover completely. In some cases, chronic recurrent diarrhea will develop from acute giardiasis which lasts for 2 years and includes symptoms such as headaches, muscle pain, and weight loss (Walker, 1998). The treatment for giardiasis is effective and usually cures the illness in 7 days. Death rarely occurs as a result of *G. lamblia* infection, accept in situations of extreme dehydration, resulting in a mortality rate of less then 0.1% (Pennardt, 2004).

Disease outbreaks of Giardiasis are most frequently attributed to waterborne transmission. These *Giardia* outbreaks occur in many provinces across Canada annually. The

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[32] A trophozoite is a protozoan in the active, feeding stage of its life cycle.
[33] Giardiasis is also known as 'Beaver Fever' because beavers are frequent carriers of *Giardia* and shed it into natural waterways. Infection with *Giardia* has been common among campers drinking stream or river water (Stiefelmeyer, 2003).

number of incidents in British Columbia are particularly high with over 1,000 outbreaks every year (Isaac-Renton et al., 1996). Water contamination with this organism is largely due to human sewage effluent and agricultural runoff (Olson, 2001). Guselle et al (1999) conducted a study involving 1602 animals and 50 farms and found that *Giardia* was documented in 70% of farms and in 8.5% of fecal samples collected.

Under certain conditions, *Giardia,* and other pathogenic protozoa such as *Cryptosporidium,* can survive and remain viable for extended periods, creating a potential risk to the quality of source watersheds. The overall survival duration for *G. lamblia* is much shorter than the bacterial pathogens described in the previous sections. As depicted earlier in Table 4.1, the study by Olson (2001) shows that holding manure as slurry provides the ideal environment for *Giardia* parasites to live, with a survival time of 1 year. This author also found that *Giardia* cysts in soil, water and manure are inactivated by freezing, desiccation and by composting. Warmer temperatures were observed to accelerate the inactivation process. Therefore, the cooler seasons in Ontario (fall and early spring), when temperatures are above freezing, provide the ideal climate for this pathogen to proliferate.

G.lamblia is a threat to source water due to its environmental perseverance, resistance to treatment processes, and high excystation rate of this parasite by its hosts. The low infective dose and significant capability to cause disease are additional factors which heighten the risk of this organism to public health.

4.4 *Cryptosporidium parvum*

Cryptosporidium parvum is another gastrointestinal parasite and is the only species in the Cryptosporiidae family capable of causing human disease. The life cycle for this protozoan is similar to *Giardia* though slightly more complex, undergoing gametogony[34] and schizogony[35] within the intestinal epithelium of humans and other mammals. The gametogony cycle produces the oocyst, the infective form of the organism (Walker, 1998). In this quiescent state, the encystment of the protozoan helps the organism withstand unfavorable conditions, analogous to *Giardia* cysts. It was shown by Hickman et al. (2000) that the cyst wall acts to protect the microorganism from desiccation, extremes in temperature, and water treatment processes. The

[34] Gametogony is the sexual reproductive cycle of protozoa (Hickman et al., 2000).
[35] Schizogony is the asexual reproductive cycle of protozoa involving multiple fission (the simultaneous division of a single cell into multiple cells) (Hickman et al., 2000).

resistance of *C.parvum* to disinfection measures such as chlorination and sand filtration techniques commonly utilized by water treatment facilities renders this pathogen particularly hazardous to drinking water.

Once the *C.parvum* cyst is ingested, the excystation of the oocyst occurs and releases 4 sporozoites[36] which then adhere to the epithelial lining of the gastrointestinal tract at which time infection begins (Health Canada, 2004). Research has determined that a range of between 10 and 100 *C. parvum* organisms is needed to generate infection in humans and animals (Health Canada, 2004; Miller *et al.*, 1986; Ernest *et al.*, 1987). Most individuals infected with *C.parvum* develop an intestinal illness known as Cryptosporidiosis. This disease is accompanied by watery diarrhea, cramping, nausea, and vomiting which can persist for several weeks. In most circumstances, this illness is self-limiting (Fawell and Nieuwenhuijsen, 2003). Unfortunately, there is no adequate treatment for Cryptosporidiosis and it can lead to a life-threatening form of watery diarrhea especially detrimental to children, the elderly, and the immuno-suppressed (Stiefelmeyer, 2003; Walker, 1998). *C parvum* was responsible for the largest recorded waterborne disease outbreak in US history, occurring in Milwaukee, Wisconsin in 1993. In this incident, *C.parvum* contamination of the city's drinking water supply resulted in more than 400,000 people becoming ill, and the death of 80 others (Walker, 1998).

Similar to *Giardia*, *C.parvum* oocysts are spread through the fecal-oral route, typically from water contamination by human and animal feces (Olson, 2001). Smith and Rose (1990) determined that infected human hosts can excrete up to 10^{10} oocysts/g feces. Spread of *C.parvum* from human to human is an important means of transmission and is often observed when water contaminated with human effluent is consumed. Based on stool samples, the prevalence rate of humans infected with *Cryptosporidium* ranges between 0.6 to 20% (Health Canada, 2004; Caprioli et al., 1989; Zu et al., 1992; Mølbak et al., 1993; Nimri and Batchoun, 1994).

C.parvum is capable of inhabiting a wide variety of animals, in addition to humans, including cattle, lambs, goats, birds, pigs, horses and monkeys (Health Canada, 2004; Stiefelmeyer, 2003). In Health Canada's Guidelines for Canadian Drinking Water Quality (2004), it is noted that despite the variety of potential hosts for *C.parvum*, lambs, calves and adult cattle are predominantly accountable for zoonotic transmission to humans (see Table 4.2

[36] A sporozoite is a stage in the life history of many sporozoan protozoa; released from oocysts (Hickman et al, 2000).

for a summary of the infection prevalence and transmission abilities of *C.parvum* in various animals).

Table 4.2: Occurrence of *Cryptosporidium* in Livestock Manure

Farm Type Source of *Cryptosporidium*	Source	Farms Testing Positive at Least Once (%)	Animals Testing Positive at Least Once (%)	Total Samples Testing Positive (%)
DAIRY				
Feces	Ruest et al. (1988)	88%		
Feces	Garber et al. (1994)	59%	all calves - 22.4% 1-3 wk - 48% 3-5 wks - 22% <5 wks - <15%	
Feces	Olson et al. (ca.1996)		20%	
Solid manure	Fleming et al. (1997)	65%		8.10%
Liquid manure	Fleming et al. (1997)	50%		7.30%
BEEF CALVES				
Feces	USDA (1993)		Diarrhetic - 40% Non-Diarrhetic - 42%	Diarrhetic - 20% Non - Diarrhetic - 11%
SWINE				
Feces	Olson et al. (ca.1996)		11%	
Feces - with slotted floors	Xiao (1994)		Nursing pigs - 0% piglets - 0% sows - 0% weanlings - 27%	
Feces - with concrete floors	Xiao (1994)		Nursing pigs - 29% piglets - 7% sows - 0% weanlings - 19%	
Liquid manure	Fleming et al. (1997)	90%		26%

* Source : Fleming et al., 1999.

Further, research has established that cattle are the primary host for this organism, shown in Table 4.3 (Olson, 2001).

Table 4.3: Prevalence of Enteric Pathogens in Humans, Cattle, Pigs and Poultry

Pathogenic Microorganism	Human	Cattle	Swine	Poultry
Salmonella	1.0%	0.0-0.1%	0.0-0.3%	10.0%-100.0%
E.coli O157:H7	1.0%	16.0%	0.4%	1.3%
Giardia lamblia	1.0-5.0%	10.0-100.0%	1.0-20.0%	0.0%
Cryptosporidium parvum	1.0%	**1.0-100.0%**	0.0-10.0%	0.0%

* Source: Olson, 2001.

This might explain the studies showing that while sewage effluent discharged into waterways is responsible for elevated *Giardia* levels, input from non-point sources, such as run-off from agricultural land, are implicated as the leading cause of elevated *C.parvum* levels (Lechevallier et al, 1991). Health Canada (2004) and Smith and Rose (1990) reported that the prevalence of *C.parvum* oocysts in cattle is greater in younger calves than mature adults, with calves excreting up to 10^7 oocysts/g feces.

Grazyk et al. (2000) determined that *C.parvum* is able to retain its infectivity in the environment for long periods of time, especially when associated with fecal material. The ability of *C.parvum* to survive in manure and soil media allows this pathogen to be transported in runoff from fields or in manure storage drainage into water sources where it can continue to persist (Stiefelmeyer, 2003). Lechevallier et al. (1991) examined raw water supplies of 66 surface water filter plants, in Canada and the USA, for the occurrence and distribution of both *Cryptosporidium* and *Giardia*. This research found that both protozoa are widely distributed in the environment, yet *Cryptosporidium* was 1.5 times more numerous on average in the samples than *Giardia*. These authors also made a notable observation that the majority of cysts and oocysts observed in the samples were not viable. Despite the ability of *Cryptosporidium* to withstand harsh environmental conditions, the presence of *C.parvum* oocysts in the environment does not necessarily confer viability. Kato et al. (2004) studied the environmental inactivation of *C.parvum* in soil, and found that after 120 days, only 10-30% of the organisms remained viable. As this study suggests, even though the viability of *C.parvum* in the environment is low, the threat still exists for this organism to reach surface water and groundwater in its virulent state.

Olson et al. (1999) studied the survival rate of *Cryptosporidium* and found that they survive best at lower temperatures (-4°C to 4°C). As with *G.lamblia*, *C.parvum* oocysts are able to survive for months in cold water and are impeded by warmer temperatures (see Table 4.1), but unlike *G.lamblia*, they are able to resist freezing (Olson, 2001). Research has also determined that composting is an effective means for the inactivation of *C.parvum*, even though it does not occur as quickly as the composting inactivation of *G.lamblia* (Olson, 2001).

The presence of *Cryptosporidium parvum* in Canadian surface waters is problematic owing to its ability to evade conventional water disinfection methods used to treat drinking water. This trait, coincided with the persistent survival dexterity, transport mechanisms, low infective dose, and virulent human health capabilities of this organism, compels the need for extra precautionary measures to guarantee the elimination of *C.parvum* from drinking water. The multiple barrier approach, including source water protection, is imperative in the prevention of *Cryptosporidium parvum* contamination of public water supplies.

4.5 Pathogenic Threats to Water Quality: Summary

In order to determine the significance of pathogenic threats to source water, the identification of common water-borne pathogens and their characteristics is paramount. The research presented in this chapter has distinguished four pathogens which pose the greatest risk to source watersheds, including *E.coli O157:H7*, *Salmonella*, *Giardia lamblia*, and *Cryptosporidium parvum.* These microorganisms have been responsible for inflicting severe and on-going disease in human beings throughout Canada and the world. Extensive studies have shown that these pathogens all present significant threats to water quality and public health due to the individual nature of their infectivity, virulence, environmental resistance and enduring survival. It is difficult to rank the level of significance presented by each pathogen in the order of high, medium or low because each organism possesses unique characteristics with detrimental effects. Therefore, each of these four pathogens represents a high significant threat to the quality and safety of drinking water resources. It is also important to associate these common microbiological threats with their common sources in source water protection areas.

Chapter Five: Origins of Pathogenic Threats to Source Watersheds

5.1: The Delineation of Pathogen Sources

Source water can originate from either surface or groundwater. Essentially, watersheds[37], which encompass both surface and groundwater, are the primary units for source water protection. The Ontario Ministry of the Environment, MOE, (2004c) defines a watershed as "an area of land that drains downwards towards lower elevations and converges at rivers or lakes" (MOE, 2004c). Pollution Probe (2004) estimates that 74% of all Canadians obtain their drinking water from surface water sources, while 26% of Canadians rely on groundwater. Surface water is found above ground, is open to the atmosphere and includes creeks, streams, rivers, lakes, and oceans. In contrast, groundwater is located beneath the Earth's surface and percolates into the ground between soil particles or cracks and fissures (Pollution Probe, 2004). All watersheds, including surface and groundwater sources, are susceptible to contamination by natural or anthropogenic means (MOE, 2004c). Ongerth et al (1995) determined that a watershed with higher human use had an increased rate of water contamination than a watershed affected by less human activity. All unprotected source waters are at risk of contamination by point[38] or non-point[39] sources of pollution.

In the White Paper on Watershed-based Source Protection Planning, the MOE recommends that the management of threats be determined on a site-specific basis according to the level of risk a threat poses to a water source (MOE, 2004c). In agreement, The Technical Experts Committee's (TEC) report to the Minister of the Environment (2004) recognized that a local assessment of threats is necessary to determine the amount of risk posed, because a generic 'ranking' of threats could not be effectively applied across the entire province (TEC, 2004). Yet, this committee acknowledged that there are certain risks that continue to impact drinking water sources in Ontario and other jurisdictions and are thus referred to as the 'Threats of Provincial Concern'. This list of source water threats includes both chemical and biological (pathogenic)

[37] A watershed may also be referred to as a 'catchment area' or 'drainage basin' (The Ontario Ministry of the Environment, 2004c).
[38] Point sources discharge pollutants directly into the environment (examples include: landfill site leachate or industrial discharges).
[39] Non-point source (diffuse) contamination occurs when water running over land collects pollutants and either enters surface water or percolates through the ground into a source watershed (example: agricultural runoff).

risks (refer to Table 3.9). The pathogenic threats to source water highlighted by the Technical Experts Committee include:

- storage and land application of biosolids and septage;
- storage and land application of manure;
- sanitary sewage and septics (including: sewer main breaks, sewage treatment plant effluent, septic system overflows, sewage treatment plant by-passes, combined sewer overflows, and sanitary sewer overflows);
- stormwater infiltration; and
- water treatment plant waste water backwash.

These five categories will be discussed in the following sections in order to emphasize the degree of risk presented by each as an assessment of significant threats to source water.

5.2 Biosolids and Septage

The term biosolids stems from the common method through which it is produced, the biological processing of wastewater solids (Synagro Technologies Inc., 2005). They are nutrient rich organic materials that have been disinfected by wastewater treatment. The removal of pathogens is critical to safe and responsible biosolids management and can be accomplished through the use of digestion, high–temperatures or stabilization processes (Synagro Technologies Inc., 2005). Following treatment, biosolids are frequently applied to agricultural land as fertilizer to improve and maintain productive soils and stimulate plant growth. Some biosolids are land-applied as a liquid while others are dewatered and have the consistency of wet soil. As stated by the Pennsylvania Department of Environmental Protection (PDEP), when applied according to state regulations and good farming practices, biosolids pose minimal or no risk to ground or surface water quality, but warns that the user must be careful not to over-apply (PDEP, 2005). The *Ontario Nutrient Management Act* (2002) was enacted in September of 2003 and set out four regulations which specifically limit the land application of biosolids and residuals. These regulations include:

1. Requirement for a 20 metre (66 feet) buffer along all surface water courses (O. Reg. 267/03, s. 45);

2. Banning of the use of high trajectory guns for land application (O. Reg. 267/03, s. 49 (1));
3. Banning of land application of sewage biosolids only from December 1st to March 31st; (O.Reg 267/03, s. 47 (1a)); and
4. Banning of sewage biosolids application where the soil is snow-covered or frozen (O.Reg 267/03, s.47 (1b))(Payne, 2003).

Approximately 388,700 dry tonnes of biosolids are produced annually in Canada (Apedaile, 2001; CH2MHill Canada, 2000). About 43% of these biosolids are applied to land, 47% are incinerated and 4% are sent to landfill, with the remainder used in land reclamation and other uses (Apedaile, 2001). Comparatively, Europe and the USA apply about 34% and 60%, respectively, of their biosolids onto agricultural land.

Despite the regulations governing the application of biosolids to farmland, controversy remains concerning the human health risks associated with the recycling of biosolids through agricultural spreading. Evidence, through research, has shown that biosolids may not be completely eradicated of pathogens following wastewater treatment. According to the Virginia Department of Health (2005), 1 billion fecal coliform bacteria are contained in 100 ml of untreated sewage. Following wastewater treatment, the number of fecal coliforms found in biosolids ranges from 30 thousand to 6 million organisms per 100 ml. Similarly, an average of 8,000 *Salmonella* bacteria are found in raw sewage and 3 to 62 *Salmonella* organisms are found in 100 ml treated sewage. The National Research Council, NRC, (2002) addressed in its report the inadequacies of the EPA's Part 503 Rule in identifying pathogenic risks posed by biosolids. The NRC felt that the pathogen standards set out by Part 503 were technologically-based, and suggested that a risk assessment-based approach is needed to accurately determine acceptable requirements to reduce pathogens in biosolids (NRC, 2002). Reilly (2001a) found that little provincial legislation in Ontario dictates the extent of treatment needed prior to land application of biosolids. Requirements for sewage treatment are not consistent among wastewater facilities and may not be detailed in a Certificate of Approval or permit from the provincial Ministry of the Environment (Reilly, 2001a). Although the majority of waste water treatment facilities are successful at reducing the numbers of pathogenic organisms found in sewage sludge, complete annihilation of these virulent microorganisms is not always accomplished. Given the low infective doses characteristic to the pathogens discussed earlier in this chapter, the presence of only a small quantity of pathogens in biosolids can be detrimental to source water quality and create a large risk to human health.

Presenting a greater risk to environmental and public health, the province of Ontario currently allows the spreading of septage, which is untreated sewage waste pumped out of septic tanks and abbatoir waste, onto rural land (Reilly, 2001b). Yet, the Ministry of Ontario is committed to phasing-out this practice. On November 20, 2004, on behalf of the Ontario Ministry of the Environment, the Honorable Leona Dombrowsky vocalized "our plan to end the practice of applying untreated septage on land... This is an extremely important commitment to me" (Dombrowsky, 2004). In this speech, Dombrowsky acknowledged the need to treat septage before its application to farm land, in order to assure that source water is protected from contamination.

Land application is not the only disposal strategy for septage used in Ontario. In 2001, approximately one third of the septage generated in Ontario was spread on land (Reilly, 2001a). The remaining two thirds were either incinerated or sent to landfills. A waste incinerator is a device, mechanism or structure constructed primarily to thermally treat waste for the purpose of reducing its volume, or destroying hazardous chemicals or pathogens present. Given the concerns about fly ash and the emission of particulates such as cadmium, mercury and polychlorinated dibenzodioxins (PCDDs), this practice is slowly diminishing and is soon to be abolished in Ontario (Monteith, 2001).

Sanitary landfills are a form of septage burial employed as another septage disposal approach in Ontario. However, problems affiliated with sanitary landfills are the production of leachate and odor, its high costs, and space limitations. The current restraints surrounding the present methods of septage disposal in Ontario present the need to acquire new technologies. Alternative septage disposal methods employed in other jurisdictions include alkaline stabilization, dewatering trenches, treatment lagoons, and composting.

Composting is a well understood and effective option for the treatment of septage and biosolids. It is an aerobic biological process analogous to sewage treatment, designed to decompose the organic matter of solid waste (Ontario Ministry of Environment and Energy, 1991). The most widely used composting technologies include windrows (turned or static), aerated static piles, and in-vessel treatment. The windrow method involves raw material stacked into an elongated pile of a triangular shape. In turning, windrows are torn down and reconstructed by mechanical means and multiple turnings ensure proper composting conditions are achieved (Ontario Ministry of Environment and Energy, 1991). In contrast, static windrows do not provide ideal composting conditions because they are not turned and rely on the natural diffusion of oxygen into the pile. The aerated static pile method incorporates either injected air into the compost material, or inducted (drawn) air, or both (Ontario Ministry of Environment and Energy, 1991). Lastly, in-vessel type systems are used to optimize aeration, temperature and moisture conditions by using rotating drums, channels, or horizontal/vertical systems. Heat is the primary factor in all composting strategies needed for the inactivation of pathogens. In the high rate stage of composting, a minimum temperature of between 55°C and 60°C must be maintained in the chamber in order to accommodate bacterial growth and subsequently pathogen elimination (Ontario Ministry of Environment and Energy, 1991). Godfree and Farrell (2005) studied the effect of sludge treatment on pathogens and found that composting was the most efficient at reducing coliform bacteria, parasites and enteric viruses by 2 to >4 log.

The dewatering[40] of septage prior to composting is a common practice in many regions of Canada, excluding Ontario (Ontario Ministry of the Environment, 2004a). Dewatered septage is mixed with a bulking agent and aerated mechanically by turning the septage. The dried product can then be used as a soil additive. Composting is advantageous for the treatment of sewage waste prior to land application because the water quality concerns of liquid runoff resulting from the spreading of liquid septage and biosolids are reduced (Henderson Paddon and Associates Ltd., 2004).

In Ontario, storage lagoons are commonly used to hold septage prior to land application. However, this type of lagoon does not treat septage and thus does not aid in the removal of pathogens (Ontario Ministry of the Environment, 2004a). In other jurisdictions, stabilization lagoons are employed for the treatment of sewage sludge[41]. These types of lagoons are best suited for rural areas where large areas of land are available. However, stabilization lagoons are not as effective during winter months and may not meet provincial standards if not designed properly (Ontario Ministry of the Environment, 2004a).

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[40] Dewatering is a process of separating the liquid fraction of septage from the solid fraction. A press method is typically used, although centrifuging, filtering, settling, or evaporation may be used as dewatering techniques (Ontario Ministry of the Environment, 2004a).

[41] Sewage sludge is the term used to describe the solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works (National Research Council, 2002).

Alkaline[42] stabilization, also known as liming, is another option for septage treatment currently being reviewed by the government of Ontario. According to Leona Dombrowsky, "Ministry of the Environment staff are looking at expanding the use of lime in Ontario" (Dombrowsky, 2004). In alkaline stabilization, lime is added to raw septage to lower the acidity as a means of destroying microbial pathogens and to inhibit their growth within the sludge material (Ontario Ministry of the Environment, 2004a). Research conducted by Godfree and Farrell (2005) found that the liming process was highly effective for the elimination of enteric pathogens, and resulted in the complete annihilation of all bacterial species. These authors also found that the effectiveness of the lime process against *Cryptosporidium* ranged from a 2 log loss in viability to no loss.

The evidence suggests that the spreading of biosolids and septage onto agricultural land allows the potential for microbial pathogens to migrate through the soil and into surface and groundwater. Clearly, septage poses a higher risk to source water given its lack of treatment. However, biosolids remain a significant threat because, although biosolids undergo treatment and disinfection processes before application to land, the viability of pathogens in biosolids following treatment has been found to persist. The storage of these sewage sludges can also present a contamination risk to source water given the possibility of storage tank leaks, breaks and overflows. Unfortunately, the current alternatives to land application in Ontario, incineration and landfills, are problematic because they emit pollutants into the environment, produce odours, and elevate costs. However, the upcoming *Drinking Water Source Protection Act* will force policy advisors and government officials to find and use new methods of septage and biosolids disposal in order to demonstrate due diligence[43] in the preservation of source water resources and human welfare.

5.3 Manure

Manure is defined as the urinary and fecal excretion of livestock and poultry, and has also been found to contain bedding, spilled feed, water or soil (University of Minnesota, 1999). According to Statistics Canada (2005), in 1996, Canadian livestock produced approximately 361

[42] Alkaline is a term used to describe substances that have a higher value than 7 on the pH scale (USEPA, 2005)
[43] Due diligence refers to the legal defense available to a person /entity having undertaken reasonable measures to comply with the requirements of the act, and taken reasonable care to prevent the prohibited act, and be able to provide evidence to that effect (Greenbaum et al., 2002).

million kilograms of manure daily amounting to an annual total of 132 billion kilograms. Beef cattle were responsible for producing 52% of this livestock manure, followed by 19% dairy cattle, 16% hogs, 7% calves, 3% poultry, 3% horses, and less than 1% contributed by sheep. Shown in Appendix 5.1, the Canadian provincial regions responsible for generating the largest amounts of manure in 1996 were the southern parts of Alberta, Saskatchewan, Manitoba, Ontario, and south-eastern Quebec. The value of manure is largely attributed to its nutrient content which can vary considerably depending on animal species, diet, bedding, and storage conditions. Table 5.1 shows a comparison of manure composition among various livestock species. Nitrogen, Phosphorus, and Potassium are nutrients found in manure, regardless of its zoological origin, and are essential for plant growth.

Table 5.1 Fresh Manure Composition According to Livestock Species

Species and Manure Component	Proportion %	Nitrogen (N) %	Phosphorus (P) %	Potassium (K) %
Horse				
Feces	80	0.55	0.13	0.33
Urine	20	1.35	trace	1
Cow				
Feces	70	0.4	0.09	0.08
Urine	30	1	trace	1.12
Pig				
Feces	60	0.55	0.22	0.33
Urine	40	0.6	0.04	0.37
Sheep				
Feces	67	0.75	0.22	0.38
Urine	33	1.35	0.02	1.74

*Source: NRCC (1983) and MacLean & Hore (1974).

Other elemental components in manure include Calcium, Magnesium and Sulfur. Azevedo and Stout (1974) and the NRCC (1983), showed that the dry material of chicken manure contained 8.1% Calcium, 0.63% Magnesium, and 0.68% Sulfur. Given the natural richness of manure, the spreading of livestock and poultry manure as an agricultural fertilizer is a common practice in Ontario and throughout the world. This process benefits the agriculture industry by providing nutrients and rich organic matter needed for plant growth and the maintenance of soil fertility.

The advantages of manure spreading are also coupled with serious dangers posed by the application of manure on soil surfaces. Many studies have shown that manure can harbor copious amounts of disease-causing organisms. Jiang et al. (2002) and Stiefelmeyer (2003) found that manure excreted by cows can contain up to 10^{10} colony forming units (CFU) of bacteria per gram. Researchers have devoted a great deal of attention to manure-borne pathogens and have found the continual presence of *Salmonella*, *E.coli O157:H7*, *Giardia lamblia*, and *Cryptosporidium parvum* in livestock manure. Olson et al. (1996) studied the fecal samples from 104 cattle, 89 sheep, 236 pigs, and 35 horses from 20 farms at up to 6 different locations in Canada. These authors found that *Giardia* was present at all 20 farms with an overall prevalence for cattle, sheep, swine, and horses of 29%, 38%, 9%, and 20% respectively. The incidence of *Cryptosporidium* oocysts in fresh livestock manure was investigated by Fleming et al. (1997), for which 552 samples at 60 farms across Ontario were tested. The results of this study showed that 26% of all swine manure samples tested positive for *Cryptosporidium*, compared to 8.1% for dairy with solid manure, and 7.3% for dairy with liquid manure (Fleming et al., 1997)[44].

Even though cattle are the primary reservoir for *E.coli O157:H7*, the prevalence of fecal shedders in dairy cattle is, in most cases, less than 1% (Kirk, date unknown). Nevertheless, since *E.coli* shed in manure is estimated to be 50,000 cfu per gram of feces (Kirk, date unknown), and as few as 10 cfu of *E.coli* are able to initiate infection, a single cow shedding *E.coli* into the environment would be a public health risk. Similar to *E.coli*, the primary carriers of *Salmonella* are cattle, but unlike *E.coli*, cattle infected by *Salmonella* generally excrete fewer than 1000 organisms per gram of manure (Clinton et al., 1979; Stiefelmeyer, 2003). Goss et al. (2001) and Stiefelmeyer (2003) found that although cattle can produce a large number of *Salmonella*, swine and poultry manure contain the greatest number of *Salmonella* organisms in livestock operations (Goss et al., 2001). Once deposited by livestock onto agricultural land, pathogens are able to survive for long periods of time and can be transported through soil and in runoff until source water is reached. Following transport, pathogens can live viably in water environments for significant periods of time creating the potential for contaminated drinking water.

Manure can be collected and stored in solid, semi-solid and liquid forms. The *Nutrient Management Act (2002)* and *Regulation 267/03* of the *Act* regulates the storage, handling, and application of nutrients (manure) applied to agricultural land for the protection of surface and groundwater resources. However, this *Act* is not directly focused on pathogens and Stiefelmeyer (2003) estimated that the *Nutrient Management Act* (2003) regulations could not protect source

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[44] For a summary of *Cryptosporidium* prevalence in livestock manure see Table 4.2.

water from pathogens released by manure operations. The degree to which livestock manure contaminates source water can vary with management practices. The temporary storage of manure prior to application is a relatively successful method used by farmers to reduce the pathogen content of manure. Goss et al (2002) discovered that bacterial populations change considerably during storage, influencing the survival of pathogens by varying levels of dissolved oxygen and temperature. Ghimire et al. (2003) found that the survival time of pathogenic organisms under storage conditions decreased with increases in oxygen content, increases in self-heat generation, high ambient and storage temperatures, and low solid content in slurries. Fleming et al. (2004) found through studies with *Salmonella*, that covering manure storages, manure depth and manure age did not play a significant role in the survival of pathogenic bacteria in manure storages.

With regards to protozoa, Fleming et al. (1999) studied the amounts of viable *Cryptosporidium* in livestock manure storages. This study involved the sampling of 60 swine liquid manure sites in Ontario. Results showed that 37% of samples taken contained *Cryptosporidium* oocysts of which 86% were viable. These findings demonstrated that conditions in manure storages did not appear to cause the complete die-off of protozoa (*Giardia* and *Cryptosporidium*). As a comparison, research gathered by Olson (2001) showed that while *Salmonella* can survive in manure slurry for 13-75 days, *Cryptosporidium* has the ability to survive in the same medium for more than 365 days.

The type of structure used for manure storage varies depending on the nature of the livestock or poultry operation and manure management system (OMAF, 2004c). Semi-solid and liquid manure is stored in either in-ground earthen or concrete tanks, above-ground concrete or steel tanks, or in under-barn concrete storage systems. Conversely, solid manure is stored in piles, usually near the barn or in the fields where spreading is to occur (OMAF, 2004c). Piles are typically placed directly on the ground or on open or covered pads. Appendix 5.2 shows the Minimum Distance Separation (MDS) between permanent manure storage structures and neighboring land uses suggested by the Ontario Ministry of Agriculture and Food (2004c). Although MDS is not a requirement of the *Nutrient Management Act* (2002), it is enforced by many municipalities. Manure is allowed to be stored temporarily in a solid form as long as it meets the criteria outlined in the *Nutrient Management Act* (2002) ***Regulation 267/03*** **(O. Reg. 267/03, s.83).**

The Ontario Ministry of Agriculture and Food, Best Management Practices outlines the typical methods used for manure spreading. The technique chosen by the operator is influenced by the type, size and number of animals on the farm, the available time in the manure application season, the acreage and crop, the economics of the collection, and the transfer and storage system and spreading equipment available (OMAF, 2004c). Manure is typically spread twice a year between April and December and timing depends on the type of crop being grown. The *Nutrient Management Act (2002) Ontario Regulations 267/03* stipulate that solid manure, applied to soil, must be tilled[45] within 24 hours of being applied (O. Reg. 267/03, s. 42 (6)). The risk of surface water or groundwater contamination is higher with liquid than solid manure, although both pose a risk to source water (Fleming and MacAlpine, 2004). Liquid manure is commonly applied by tank spreaders or by tractor-pulled flexible hose and can be spread over the soil surface or injected into the soil (OMAF, 2004c). The land application standards for nutrients set out in the *Nutrient Management Act (2002) Ontario Regulations 267/03* can be found in Appendix 5.3 and are reinforced by the Best Management Practices developed by the Ontario Ministry of Agriculture and Food. However, research conducted by Stiefelmeyer (2003) suggests that these regulations do not provide sufficient pathogen control for public health protection.

Agricultural effluent has been identified as a significant source of water resource contamination mainly due to the environmental impacts of runoff. Olson et al. (1996) found that agricultural effluent caused elevated *Giardia* levels in surface water. Runoff is defined by the *Nutrient Management Act (2002) Ontario Regulation 267/03* as,

"a liquid that,

(a) has come into contact with manure in a permanent nutrient storage facility, temporary field nutrient storage site, outdoor confinement area or farm-animal yard lined with concrete or other paving material of equal or lesser permeability,

(b) may contain components of manure in solution or suspension, and

(c) is no longer contained in the permanent nutrient storage facility, temporary field nutrient storage site, outdoor confinement area or farm-animal yard"(OMAF, 2003).

Runoff control is an important component of any manure storage and application system for the prevention of source water infiltration of pathogens. However, this has been found to be difficult

[45] "Tillage" is the mechanical process of disturbing the soil so as to be turned, mixed, or displaced from its undisturbed state (OMAF, 2003).

given that rainfall is a predominant factor in the transport of microorganisms in runoff (Stiefelmeyer, 2003). In a 1993 study involving 39 interviews with beef, dairy, poultry, and hog producers in southwestern Minnesota, respondents admitted that they had difficulty keeping their manure storage facilities from overflowing during periods of heavy rainfall (Schmidt et al., 2004).

The proven existence of pathogenic organisms in livestock manure and their ability to be horizontally transported into the subsurface through runoff, confirms the significant threat imposed upon source water by manure operations. The susceptibility of water resources to pathogen contamination is intensified by the insufficiencies of the *Nutrient Management Act (2002)*. Therefore, since current manure management strategies within Ontario do not protect water resources from pathogen contamination, source water protection regulations are critical for the reduction of microbial risks to source watersheds posed by manure storage and application practices.

5.4 Sanitary Sewage and Septics

For centuries, pathogens and biological pollutants from human wastes have plagued urban and rural areas around the world due to the lack of segregation between waste water and drinking water. It wasn't until the mid 1800s that Paris and London made the first attempts to combat water-borne disease through the construction of sewer systems (McNeill, 2000). By the late 1800s many western European and North American cities had established filtration plants to treat domestic water supplies, and the use of chlorine for disinfection was soon to follow (McNeill, 2000). At present, domestic wastewater undergoes a series of treatment processes before being discharged into surface waters. Once sewage is released into the sewer system it is carried to a wastewater treatment plant. Following treatment, the effluent is discharged into the local watershed where it becomes the source water for drinking water treatment plants. The source water then undergoes further treatment at a drinking water treatment plant before being distributed back to the community.

Essentially, sewage is the term used to describe human-generated wastewater flowing from homes, businesses and industry (SFEP, 2004). Human fecal matter is the component of sewage that presents the greatest pathogenic threat to water quality because it can contain a wide variety of disease-causing organisms. In fact, "each gram of human feces contains 10^8 *E.coli* organisms" (Walker, 1998, p.154). In Ontario, more than 5.7 million cubic meters of sewage are flushed every day down residential and commercial toilets and drains (Kapitain, 1995). It then proceeds to enter a complex series of pipes to transport the sewage to sewage treatment plants, also referred to as municipal waste water treatment plants. The city of Toronto alone maintains 487 kilometres of huge trunk mains, 9,977 kilometres of local sewers with 463,300 sewer connections (City of Toronto, 2005). Sewer systems follow the slope of the land, relying on gravity to guide sewage to treatment plants, predominantly located at lower elevations. Pumping stations[46] are also frequently used to deliver sewage to a treatment facility where the slope of the land does not provide for the effective use of gravity. Regrettably, wastewater contamination of source water frequently occurs before sewage is able to reach a treatment facility. These incidences are usually the result of sanitary sewer or combined sewer overflows. Sanitary sewers are solely responsible for the transport of wastewater released from drains, toilets, sinks and other domestic or industrial appliances. These types of sewer systems can release pathogens into the environment as a consequence of broken pipes, equipment failures (pumping station malfunctions), and overloads due to high increases in water use (USEPA, 2002d). In a combined sewer, there is only one pipe which carries both sanitary and storm drainage (City of Toronto, 2005). The potential for microbial pollution of waterways by Combined Sewer Overflows (CSO) is elevated during periods of heavy rainfall. These situations are problematic because during wet weather, the volume of water may exceed the treatment plant's capacity and some of the water overflows untreated into the nearest watershed (City of Toronto, 2005). Currently, the city of Toronto is developing a 'Combined Sewer Elimination Program" to prevent the overflow of wastewater during wet weather conditions.

Godfree and Farrell (2005) state that the original purpose of sewage treatment was to reduce environmental contamination of anthropogenic discharges into waterways. In addition, initial sewage treatment practices were not particularly concerned with the eradication of pathogenic microorganisms, but were more interested in the removal and mitigation of gross solids from water resources (Godfree and Farrel, 2005). However, developments in science and technology have conveyed the severe epidemiological effects of pathogens in the environment,

[46] Pumping stations are mechanical device installed in sewer or water system or other liquid-carrying pipelines to move the liquids to a higher level (USEPA, 1998).

and unquestionably demonstrated to policy advisors, government officials, and treatment facility practitioners the need to strictly monitor and manage these virulent microorganisms.

The quality of effluent discharged from a sewage treatment facility depends on the level of treatment that it has received. There are five categories of sewage treatment employed in Ontario sewage treatment plants which include primary treatment, secondary treatment, tertiary treatment, lagoons, and communal septic systems. These types of treatment processes are described further in Appendix 5.4. Each successive treatment process ensures a higher quality of effluent discharged from sewage treatment plants. Consequently, the effluent from a primary treatment plant poses a greater health risk than wastewater discharged from a secondary treatment facility. If wastewater is able to bypass one of the sewage treatment steps, the purity of the final effluent will be compromised. In 1995, more than one million cubic meters of sewage receiving only primary treatment were released into Ontario waters daily (Kapitain, 1995). Primary treatment of waste generally involves the settling and detention of large solids and according to Payment et al. (2001), parasites and bacteria are relatively unaffected by settling unless they are bound to larger particles.

About 20% of the Ontario residents living in small rural communities rely on private on-site septic tanks and tile fields to treat and dispose of their sewage (Ho, 1999). Consequently, there are approximately 1 million on-site septic systems used in Ontario (Ottawa Septic System Office, 2004). Septic systems provide a means of treating household waste for areas that do not have access to public sewer systems or where sewering is not feasible. The 2002 amendments to the *Ontario Building Code Act (1992)* dictate that municipalities are the primary authority for the regulation of sewage systems (including septics). These amendments to the *Act* also required that a sewage permit be issued by the municipality before any installations, extensions or alterations of a sewage system are allowed to take place.

Conventional septic systems used in Ontario consist of a septic tank and septic bed (also referred to as a weeping bed, tile bed, leach field, disposal field, or absorption field). Initially, waste water discharged from the house or building, flows into the septic tank made of concrete or sometimes steel. The septic tank acts as a settling tank[47] to hold the waste water long enough to allow solids to settle out. It is also contains natural bacteria which decompose human waste

[47] A settling tank is a holding area for wastewater, where heavier particles sink to the bottom for removal and disposal (USEPA, 1998).

products into environmentally acceptable components (Lockwood, 2004). Approximately 50% of the solids decompose in the tank, the other particles settle out on the bottom of the tank as sludge. Lighter particles form a scum at the top. This process leaves a middle layer of partially clarified water (Rideau Residents, 2004). The septic tank contains baffles that prevent any scum that floats to the surface and sludge that settles to the bottom from passing out of the tank (Lockwood, 2004). From the septic tank, the separated water flows into a small distribution box where it is then circulated out to several perforated pipes. These perforated pipes then deliver the liquid to a large soil surface area, the septic bed, for absorption. At this point, the wastewater may still contain environmental contaminants and pathogenic microorganisms. The soil acts as a filter to remove small amounts of solids and microorganisms that may be carried along with the liquid (Rideau Residents, 2004). The sludge in the bottom of the tank must be periodically pumped out and properly disposed of. If septic systems are not properly designed and maintained, they become highly susceptible to failure.

Managing septic systems requires regular maintenance, proper installation and siting, and the detection and correction of existing failing systems. Improperly functioning septic systems are recognized as a significant contributor of pollutants and disease-causing microorganisms, contributing over 1 trillion gallons of waste each year to subsurface and surface waters in the USA (Stormwater Manager's Resource Center, 2004; NSFC, 1995).

Stiefelmeyer (2003) found that vertical (the soil matrix) and horizontal (runoff) are the two predominant means of transportation used by pathogenic organisms enroute to surface and groundwater. Although vertical transport is the primary mode used in a septic system, poorly designed leaching beds may permit the horizontal travel of microorganisms to receiving waters. The efficacy of adsorption and filtration during vertical transport on the removal of microorganisms is influenced by three main factors: soil type, soil structure and rainfall. There are three types / textures of soil: sand, silt, and clay. The kind of soil texture used for a septic bed can tremendously affect the time of transport (hydraulic conductivity) and quality of effluent passing through the soil and entering the surrounding water table. Research conducted by Stiefelmeyer (2003) found several studies focused on the survival and transport of pathogens in various soil types. The main findings by this author suggest that:

- the filtration of microorganisms in soil is dependant on its texture and pore space;

- the degree of bacterial absorption, and hindrance of transport, is greatest in clay soils compared to sandy soils; and
- the transport of protozoa is greatest in silty loam soils compared to sandy soils.

Despite the absorption advantages of clay soils determined by Stiefelmeyer (2003), Lesikar (date unknown) of Texas A&M University warns that the sole use of clay soils in septic absorption beds can cause septic effluent to accumulate on the soil surface and contribute to runoff. This author explains that clay soils are unsuitable for absorption fields because of the limited pore space for holding effluent. The limited porosity of clay soils forces effluent to build up and seep to the surface (Lesikar, date unknown). Increases of moisture in the soil can also contribute to decreased efficiency of septic processes and heighten the risk of source water contamination. Research by Stiefelmeyer (2003) concluded that in rainfall events, transport of bacteria is accomplished in any type of soil.

Septic systems, as well as sewer systems, can have numerous negative impacts on water quality. Sewage pollution is a major cause of beach closures in Ontario every year. In this province, beaches are shut down when bacterial (*E.coli*) levels exceed 100 organisms / 100 ml. In 2004, all of Toronto's beaches were closed at least once for not meeting provincial quality standards (Waterkeeper Alliance, 2004). Sanitary and combined sewer overflows, breaks in sewer systems and septic system malfunctions are to blame for these instances of adverse water quality. Of greater importance is the threat posed by untreated sewage to the quality of source watersheds. In section 4.1.3, sewage effluent was identified as the primary source of *Giardia lamblia* contamination in surface waters. Earlier discussions in this chapter also depicted human waste (feces and urine) as the main source of *Salmonella typhimurium*, the strain of bacteria responsible for Enteric (Typhoid) fever. Given that the mortality rate of patients with Typhoid Fever is 2-10% and as little as one *G.lamblia* cyst can cause infection in humans, sewage is undoubtedly a source of water contamination that threatens the health of source watersheds and jeopardizes public safety.

5.5 Water Treatment Plant Waste Water Backwash

The disposal of wastewater by filter backwash in the process of operating a drinking water treatment plant can have a significant impact on the quality of source water receiving the effluent. This effluent is commonly referred to as 'Spent Filter Backwash', and is generated when finished[48] water is forced through the filter, in the opposite direction to the flow used during treatment operations (USEPA, 2002b). This process is used to clean the filter media, employed during the filtration of wastewater, by dislodging particles which have accumulated or become trapped in the filter. The particles removed by this practice may include chemical contaminants, raw water particles, and microbial pathogens. Source water is usually the receiver of backwash effluent and is thus susceptible to pathogen contamination by this process.

Conventional drinking water treatment plants use a series of treatment technologies to remove contaminants from drinking water before it can be distributed to the community. The individual processes most commonly used in drinking water treatment include filtration, flocculation, sedimentation and disinfection (Drink to Your Health, 2002). Flocculation is used to coagulate small particles into larger particles, which then settle out through sedimentation. Filtration is an important step in drinking water treatment because not only does it remove large particles such as organic matter, silts and clays, but it also removes disinfection-resistant protozoa, such as *Giardia* and *Cryptosporidium*, from the water. Table 5.2 shows the efficiency of various filtration techniques for the removal Giardia.

Table 5.2: Effectiveness of Various Filtration Techniques for the Removal of Giardia

Filtration Process	***Giardia* (log removal)**
Direct filtration / In-line filtration	1.5 to 4.0
Conventional filtration	2.0 to 6.0
Slow sand filtration	> 3.0
Membrane filtration	> 6.0

* Source: Canadian Council of Ministers of the Environment, 2004a.

There are several types of filtration methods which may be utilized such as direct filtration, slow sand filtration, and membrane filtration, which have varying efficacy for microbial removal (See Appendix 5.5). Disinfection techniques are applied in sequence with the other treatment processes to ensure that other virulent microbes such as *E.coli* and *Salmonella* are inactivated. Chlorination with chlorine, chlorine dioxide or chloramines is the most common form of disinfection. The effectiveness of these techniques is displayed in Table 5.3. However, the use

[48] Water is 'finished' when it has passed through all the processes in a drinking water treatment plant and is ready to be delivered to consumers (USEPA, 1998).

of ozone and ultraviolet radiation has also become a popular method for drinking water disinfection.

Table 5.3: Effectiveness of Various Disinfectant Techniques on Different Pathogens

Disinfectant	Microorganism		
	E.coli	*Giardia*	*Cryptosporidium*
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

* Source Canadian Council of Ministers of the Environment, 2004a.

The quality of filter backwash water varies from plant to plant. However, studies have shown that pathogens are frequent inhabitants. Cornwell et al. (2001) investigated the prevalence of Giardia and *Cryptosporidium* in spent filter backwash from 25 water treatment plants. Of 148 samples tested, *Giardia* and *Cryptosporidium* were found to be positive in 5% and 8% of samples respectively. Protozoa are the pathogens of greatest concern in regards to filter backwash, because, unlike bacteria, they are resistant to conventional disinfection techniques, and therefore have a greater likelihood of being found in filter media. However, bacteria do remain a potential risk to receiving waters from backwash effluent discharge. In 2001, the United States Environmental Protection Agency released the Filter Backwash Recycling Rule (FBRR), which is not legally enforced, but establishes regulatory provisions governing recycling streams[49] and spent filter backwash generated by conventional and direct filtration water treatment processes. Given the apparent risks posed by wastewater filter backwash, the Technical Experts Committee included the discharge of filter backwash from drinking water treatment plants as a threat of provincial concern to source water resources.

5.6 Stormwater Infiltration

Human beings have contributed to the deterioration of water quality through industrial, domestic and agricultural activities, causing the release of pollutants into the environment.

[49] The reintroduction of water treatment effluent residuals back into the same drinking water treatment plant (USEPA, 2002b).

Globally, the use of freshwater has increased tremendously over the past few centuries and continues to escalate annually. According to McNeill (2000), total freshwater use in 1990 (withdrawing approximately 5,190 km^3) was about 40 times greater than in the year 1700 (withdrawing about 110 km^3) and even greater still than 1970 (2,590 km^3). Table 5.4 shows the estimated changes in freshwater use, divided by human activities, between 1700 and 1990.

Table 5.4: Estimated Uses of Freshwater Throughout the World

Year	Use (%)			Withdrawals (km3)
	Agricultural (Irrigation)	Industrial	Domestic (Municipal)	
1700	90	2	8	110
1800	90	3	7	243
1900	90	6	3	580
1950	83	13	4	1360
1970	72	22	5	2590
1990	66	24	8	4130
2000	64	25	9	5190

* Source: McNeill, 2000.

However, the benefits affiliated with the use of water have proven to be costly. The consequence of increased water usage is the increase in wastewater and pollution. The purpose of stormwater management is to counteract anthropogenic degradation of natural water resources for the maintenance and preservation of the hydrologic cycle[50].

Stormwater infiltration describes the mixture of rainfall and snowmelt that leaches into the ground or runs off the land into storm sewers, streams, and lakes (Ontario Ministry of the Environment, 2004b). Stormwater runoff is caused by impervious surfaces (such as roads, buildings and sidewalks) preventing the infiltration of water into the soil. Stormwater infiltration and runoff can threaten water quality by transporting pollutants found on the land into nearby surface water or groundwater sources. These potential contaminants may include lubricants, metals, pesticides, and microorganisms. The presence of pathogenic microorganisms found in stormwater may be attributed to pet wastes, sewage leaks, or even manure spills during transportation. Therefore, a stormwater management strategy must be developed and used in order to minimize the risk of pathogen contamination to watersheds.

[50] The hydrologic cycle is the continuous circulation of water around the Earth between the oceans, atmosphere and land. Water is supplied to the atmosphere by evaporation from water and other surfaces, and transpiration from plants. It is returned to the land through precipitation (Ontario Ministry of the Environment, 2004b).

In Ontario, stormwater management incorporates a 'treatment train' approach involving a combination of lot-level, conveyance, and end-of-pipe controls in order to meet provincial stormwater objectives (Ontario Ministry of the Environment, 2004b). Most lot-level and conveyance measures are used for storage and infiltration controls. Storage controls are employed to temporarily store stormwater runoff before it is released at a controlled rate, whereas infiltration controls are designed to encourage seepage of stormwater into the ground in order to maintain the natural hydrological cycle (Ontario Ministry of the Environment, 2004b). End of pipe controls are generally administered for flood or erosion prevention, or as a means of improving water quality. The Technical Experts Committee's (TEC) Report on Watershed-based Source Protection Planning (2004) showed particular concern regarding the use of stormwater collection ponds in urban areas which allow direct infiltration into the ground. The TEC conveyed in their report that this type of stormwater management practice presented a substantial risk of pathogen contamination to surrounding aquifers. There are many kinds of these stormwater collection/infiltration ponds including:

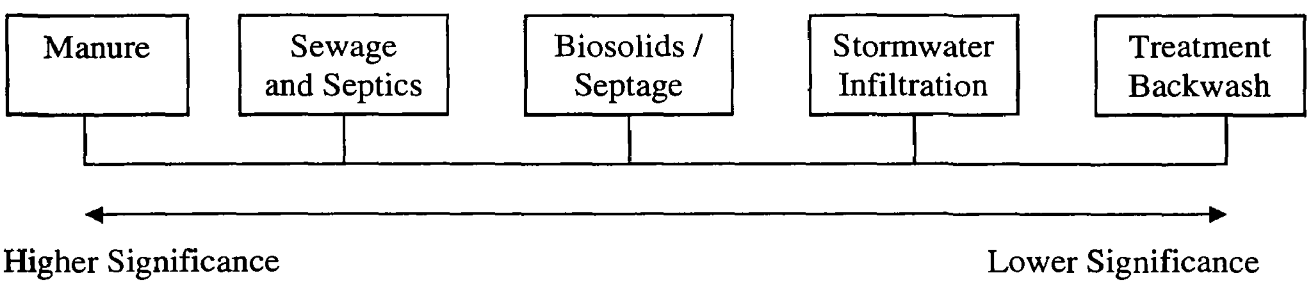
- Soakaway Pits/ Infiltration Trenches;
- Pervious Pipe Systems;
- Grassed Swales;
- Dry Ponds (the least effective for water quality control);
- Wet Ponds (most commonly used in Ontario);
- Infiltration Basins; and
- Vegetated Filter Strips.

These and other stormwater management practices are described further in Appendix 5.6. In spite of the benefits associated with stormwater collection ponds, these systems have the ability to provide a direct route for sewage-borne or manure-borne pathogens to reach source watersheds. The increase in water flow during heavy rains, or the effects of improperly designed stormwater collection ponds are conditions which heighten the potential for watershed contamination. Even though stormwater infiltration does not represent the highest risk to source water protection, it still remains a threat of provincial concern and must be management accordingly.

5.7 Sources of Pathogenic Threats: Summary

The primary sources of pathogens in the environment, leading to source water contamination, are important considerations in the characterization of risk significance. Across Canada, and in other jurisdictions world-wide, the origins of these sources are attributed to industrial, agricultural and municipal practices. As identified by the Technical Experts Committee and detailed in this research, the pathogen sources of greatest concern to water resources in Ontario include the storage and application of biosolids and septage, the storage and application of manure, sanitary sewage and septic system discharges, drinking water treatment backwash, and stormwater infiltration. None of these sources can be excluded from consideration as a significant direct threat. However, the degree of significance presented by each practice can be defined by the frequency of the practice around a watershed, the potential amount and variety of pathogens which may be released as a result of such a practice, and the legal parameters and requirements which confine each practice. Given these characteristics, the level of significance affiliated with each source of pathogens in the environment is illustrated by Figure 5.1 using an incremental scale.

Figure 5.1: Incremental Scale of Significance for Sources of Pathogens in the Environment.



Manure storage and application practices are highly prevalent in Ontario, have the ability to release large amounts of pathogens into the environment, and are not sufficiently regulated for pathogen management within the province. Consequently, this agricultural practice represents the most significant threat (presented by a source) to source watersheds, with sewage and septic sources posing additional risks. On the lower end of the scale is treatment backwash, which occurs less frequently in Ontario, releases a significantly lower quantity of pathogens into the environment, and although it is not heavily regulated, this practice would not contribute a great deal of source water protection with additional legal parameters. Despite these findings, all of the pathogen sources, identified by the TEC, cannot be excluded from consideration and the significance of the risk posed by each is related to the pathogen loads produced and the probability of contamination events.

Chapter Six: Failure Estimates Using Ontario Spills Action Center Spills Database

6.0 The Role of Failure in the Determination of Significance

Fundamentally, the principles of the multiple-barrier approach to source water protection are based on the abatement of failure. As discussed in Chapter Two, multiple barriers are critical to ensure the protection of drinking water quality in the event of a single barrier failure. Failure is defined as "a change in the condition of a system such that it is unable to function at its required level of performance... A failure may be produced when a fault is encountered" (NASA, 2004). The purpose of this chapter is to show that the failure probability of agricultural, industrial, and municipal systems is not zero. In fact, the non-zero probability of failure among operations with source water impacts is relatively high. The Federal-Provincial-Territorial Committee on Drinking Water and the CCME (2004a) identified six major types of failures with the ability to adversely affect drinking water supplies. These potential kinds of failures can be caused by mechanical problems, environmental damage, vandalism, intentional errors caused by disgruntled employees, power outages, communication disruptions, and accidental spills. Types and sources of failure are described further in Appendix 6.1. Regardless of the origin, the potential for failure enhances the susceptibility of source watersheds to pathogen contamination, and therefore, increases the significance of threats. The assessment of failure is a crucial step in the identification of threats and the assessment of risk significance, and should be incorporated in source water protection planning.

6.1 Spills Caused by Operational Failure

One of the most common sources of water contamination is through accidental spills (CCME, 2004). The *Environmental Protection Act (1990)* states that,

> "a spill when used with reference to a pollutant, means a discharge,
> (a) into the natural environment;
> (b) from or out of a structure, vehicle or other container and,
> (c) that is abnormal in quality or quantity in light of all the circumstances of the discharge" (Part 10, 91(1)).

There are eleven classes of spills set out by the *Environmental Protection Act (1990)*. Classes I II and IV are of greatest importance to the release of pathogens into the environment. A Class I spill would involve a discharge that is authorized by and is in accordance with a certificate of approval or permit. A Class II spill is the release of water from reservoirs formed by dams caused by a natural event, or the discharge of potable water from municipal water mains. A Class IV spill is a discharge that is a direct and unavoidable result of a planned maintenance procedure to a water or waste water system or to pollution abatement equipment, or is planned for research or training purposes (O. Reg. 675/98 – amended to O. Reg. 240/01). Under the *Environmental Protection Act (1990)*, spills of any kind, with the potential to be hazardous to the environment, are required to be reported to the Ministry. Section 13.1 of the *Act* states that,

> "every person,
> (a) who discharges into the natural environment, or
> (b) who is the person responsible for a source of contaminant that discharges into the natural environment, any contaminant in an amount, concentration or level in excess of that prescribed by the regulations shall forthwith notify the Ministry of the discharge" (Government of Ontario, 1990, c. E.19, s. 13.1).

In order to accommodate this condition of the *Act*, The Ontario Ministry of the Environment created the Spills Action Center (SAC) to deal with spills reported to the Ministry.

In the event of a spill, the SAC is primarily responsible for ensuring that whoever is accountable for the spill contains it and cleans up the site in accordance with Ministry guidelines. The SAC is staffed 24 hours a day and receives and records province-wide reports of spills and co-ordinates appropriate responses (Ontario Ministry of the Environment, 1998). Every year the SAC receives between 4000 and 5000 reports of spills from areas throughout the province. The majority of these spills can be dealt with by those responsible for the spill or by the municipality, and on occasion, the on-site presence of Ministry staff is required. For every spill reported, the following data must be collected by SAC staff:

- The date of the spill;
- The name / type of the contaminant;
- The sector / source type of the contaminant;
- The location of the spill (Municipality / County District);
- The quantity discharged;
- A description of the incident;
- The cause of the incident;

- The potential for environmental impact; and
- The nature of the impact.

The following section examines SAC spill report data from 2003 and 2004 to determine the frequency and nature of spills occurring annually within the province of Ontario.

6.2 Spills Action Center: Spills Data from 2003 and 2004

Agricultural, industrial and municipal activities have the ability to release pathogens into the environment, with the potential to contaminate source waters, if their operating systems are not managed appropriately. However, even when equipment is in good working order and used properly, accidents can still occur and spills can still take place (OMAF, 2004a). The frequency of spills within a region and from particular sources is a good indicator of the failure probabilities associated with certain practices. Therefore, the spills reported to the SAC in 2003 and 2004 were examined in order to derive pertinent information about the failure rates of watershed impacting operations, especially those identified by the TEC as being 'Threats of Provincial Concern'. In total, there were 414 and 380 spills in 2003 and 2004, respectively, with the potential to discharge pathogenic contaminants into the environment. In the following sections, these sources of spills, the types of contaminants spilled, and other relevant findings are analyzed and discussed in greater detail.

6.2.1 Geographical Distribution of Spill Reports

As of 2001, the last census year, the province of Ontario had a total population of 11,410,046 people. This population is spread out among many rural, small town and metropolitan communities throughout Ontario. As part of this study, the number of spills, as reported to the SAC, was compared to the location (county) in which the incident occurred. This information is listed in Appendix 6.2 for both 2003 and 2004. Using 2001 Census data, approximate populations were allocated to each county and then graphed in order to observe trends (seen in Figures 6.1 and 6.2).

Figure 6.1: Graph of Population Density Versus Quantity of Spills for 2003

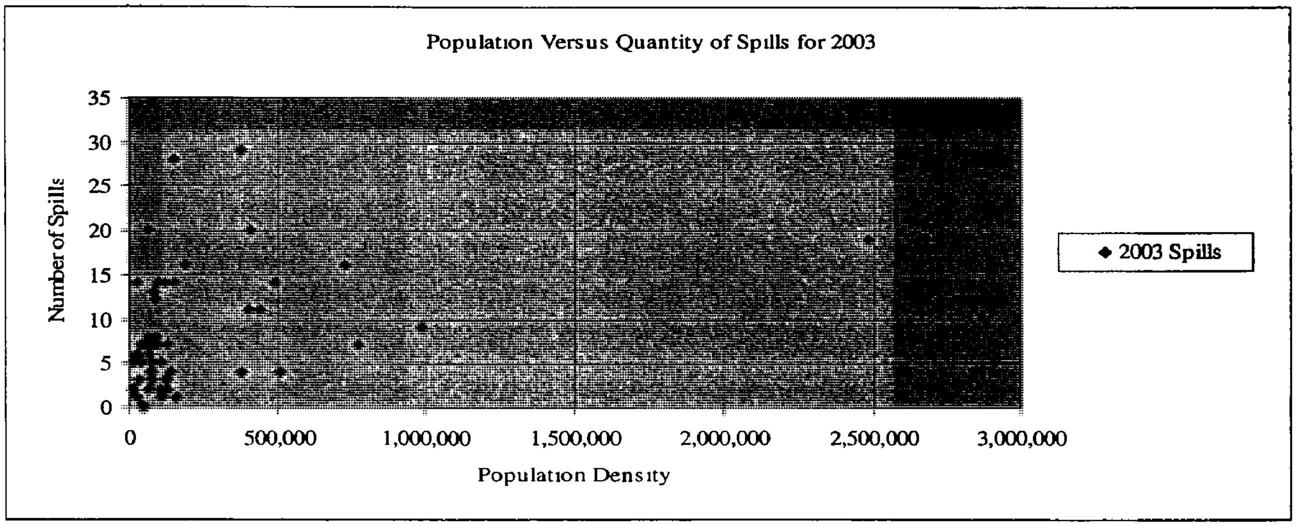
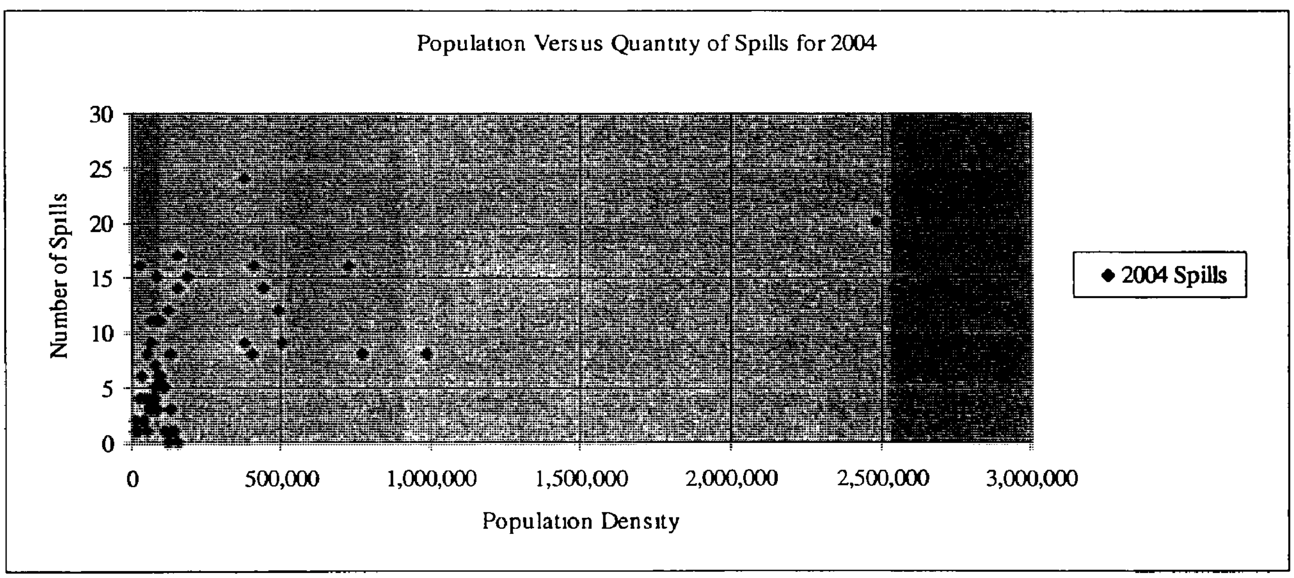


Figure 6.2: Graph of Population Density Versus Quantity of Spills for 2004



Interestingly enough, these graphs proved to be very similar in distribution, and indicated that small towns tend to experience a greater number of spills. Each graph showed a distinct concentration of counties, with fewer than 100,000 people, having between 0 and 10 spills per year. This investigation also showed that Simcoe County, having a population of 377,050 people, had the highest number of spills in both 2003 and 2004 with 29 and 24 spill events, respectively.

The Municipality of Metropolitan Toronto, with a population more than 6 times the size of Simcoe County, had considerably fewer spills in 2003 (19 spill events) and 2004 (20 spill events). This finding initiated the examination of the most common sources and contaminant types of spills in small counties compared to larger populated counties for 2003 and 2004.

For this next study, the smallest counties were chosen based on populations below 60,000 people, whereas the counties with populations of greater than 400,000 people represented larger counties. The results of this investigation showed that in 2003, the most frequent spill source in larger counties was sewer system failure at 28.8%, and the most common contaminant spilled was raw sewage at 60.4%. The second most frequent spill source in larger counties was observed to be sewage treatment plant effluent[51], at 24.3%, and the second most common type of contaminant spilled in this kind of community was sewage sludge at 9.9%. This trend was seen again in 2004. The results observed in larger counties are tabulated in Appendices 6.3 to 6.6.

In smaller counties, sewage treatment plant bypasses[52] were the major source of spills (31.6%) observed in 2003, followed by sewage treatment plant effluent at 22.8%. In the same year, primary chlorinated sewage (36.8%) was found to be the most frequent contaminant spilled in small counties, slightly higher than raw sewage spill events (35.1%). This observation changed in 2004, with raw sewage (54%) being the contaminant most often spilled, followed by primary chlorinated sewage at 20%. Sewage treatment plant effluent (30%) was found to be the leading source of contaminant spills in smaller counties in 2004, slightly higher than septic system failure (24%). The results observed in smaller counties are tabulated in Appendices 6.7 to 6.10. These findings suggest that in largely populated regions, failing sewer systems pose the greatest threat to source water quality, whereas in areas with smaller populations of people, sewage treatment plant failures are the most significant threat to source watersheds.

As a third component of this geographical investigation, the top five counties with the greatest number of spills per year, regardless of population size, were correlated with the types of contaminants spilled and the sources for each spill (see Appendices 6.11- 6.14). This study found that approximately 65% of spills, in 2003 and 2004, resulted in the discharge of raw sewage. Tables 6.1 and 6.2 display these findings as excerpts from Appendices 6.12 and 6.14.

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[51] Discharges from sewage treatment plants containing various levels of untreated sewage.
[52] The failure of sewage to undergo wastewater treatment before being discharged into the environment.

Table 6.1: Summary of the Top Five Counties with the Largest Number of Spills in 2003 and their Associated Contaminant Types

Contaminant Type	**County**					**Total**	**% of Total Spills**
	Simcoe	Toronto	Halton	Niagara	Kenora		
Raw Sewage	22	10	17	13	14	**76**	**65.5%**
Primary Unchlorinated Sewage	1	1	1	2	0	**5**	**4.3%**
Primary Chlorinated Sewage	2	0	3	0	4	**9**	**7.8%**
Secondary Unchlorinated Sewage	0	2	0	0	0	**2**	**1.7%**
Untreated Wastewater Effluent	1	0	3	0	2	**6**	**5.1%**
Final Unchlorinated Sewage Effluent	1	0	1	0	0	**2**	**1.7%**

Table 6.2: Summary of the Top Five Counties with the Largest Number of Spills in 2004 and their Associated Contaminant Types

Contaminant Type	**County**					**Total**	**% of Total Spills**
	Simcoe	Toronto	Thunder Bay	Niagara	Sudbury		
Raw Sewage	20	13	8	11	8	**60**	**64.5%**
Primary Chlorinated Sewage	0	0	7	1	5	**13**	**14.0%**
Sewage Sludge	1	3	0	0	0	**4**	**4.3%**
Untreated Wastewater Effluent	0	1	2	1	1	**5**	**5.4%**
Treated Wastewater Effluent	0	2	0	1	1	**4**	**4.3%**

It was also determined that failing sewer systems, due to sewer blocks, breaks or other problems, were the primary source of accidental spills in 2003 and 2004 at 31% and 28%, respectively. Tables 6.3 and 6.4 display these findings as excerpts from Appendices 6.11 and 6.13.

Table 6.3: Summary of the Top Five Counties with the Largest Number of Spills in 2003 and their Associated Contaminant Sources

County	Contaminant Source				
	Sewage Treatment Plant Effluent	Septic System Failure	Sewer System Overflow	Sewer System Failure	Sewage Treatment Plant Bypass
Simcoe	6	6	2	12	3
Toronto	8	0	5	4	2
Halton	7	2	0	5	11
Niagara	3	3	1	7	4
Kenora	2	4	2	8	4
Total	**26**	**15**	**10**	**36**	**24**
% of Total Spills	**22.4%**	**12.9%**	**8.6%**	**31.0%**	**20.7%**

Table 6.4: Summary of the Top Five Counties with the Largest Number of Spills in 2004 and their Associated Contaminant Sources

County	Contaminant Source					
	Sewage Treatment Plant Effluent	Septic System Failure	Sanitary Sewer Overflow	Sewer System Failure	Sewage Treatment Plant Bypass	Combined Sewer Overflow
Simcoe	5	3	4	10	2	0
Toronto	7	3	1	2	4	2
Thunder Bay	4	3	0	1	8	1
Niagara	3	0	1	4	5	1
Sudbury	3	0	1	9	3	0
Total	**22**	**9**	**7**	**26**	**22**	**4**
% of Total Spills	**23.7%**	**9.6%**	**7.5%**	**27.9%**	**23.6%**	**4.3%**

Again, county trends showed that increased population size did not correspond with the most spills province-wide. Although Toronto (with a population of 2,481,494) was among the top five, this region only had 4 sewer system failures in 2003, ranking 5th following areas with much smaller populations including the counties of Kenora, Halton, Niargara and Simcoe. A similar pattern was observed for the Municipality of Metropolitan Toronto in 2004, with only 2 failing sewer systems reported. It should also be mentioned that sewage treatment plant bypasses and sewage treatment plant effluent spills, due to system failures, were also significant contributors to spill events in the top five counties in 2003 and 2004.

Although observable patterns were evident in this investigation, further studies are needed to look at spills data over a longer time so that a more accurate estimation of geographical trends can be established.

6.2.2 Analysis of the Types of Contaminants Spilled

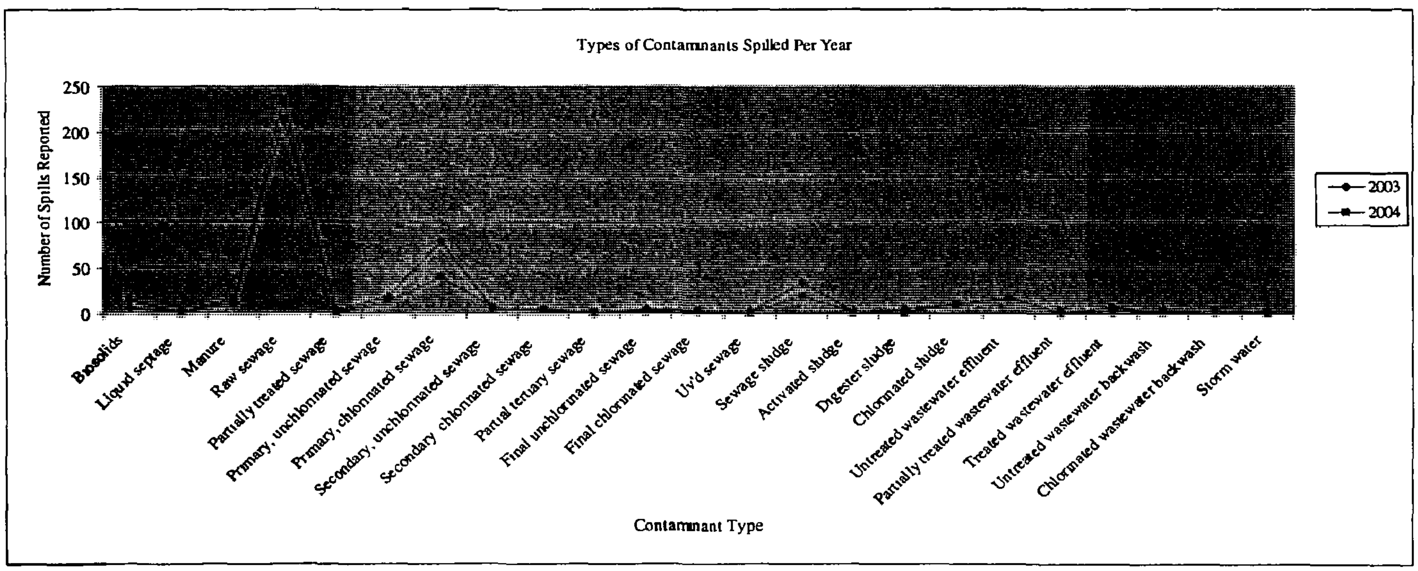
The two years of observations, 2003 and 2004, in the SAC spills database, indicate the environmental impacts caused by the events of failing systems. The extent of these impacts is largely based on the contaminants released as a result of the spills. The spills data for 2003 and 2004 depict an extensive array of pathogen-containing contaminants accidentally discharged into the environment. A summary of this information is presented in Table 6.5.

Table 6.5: Types of Contaminants Spilled in 2003 and 2004

Contaminant	**2003**	**% of Total Spills**	**2004**	**% of Total Spills**
Biosolids	6	1.4	14	3.6
Liquid septage	2	0.4	0	0.0
Manure	10	2.4	15	3.9
Raw sewage	214	**51.6**	234	**61.5**
Partially treated sewage	3	0.7	0	0.0
Primary, unchlorinated sewage	17	4.1	12	3.1
Primary, chlorinated sewage	78	**18.8**	39	**10.2**
Secondary, unchlorinated sewage	4	0.9	5	1.3
Secondary, chlorinated sewage	4	0.9	3	0.7
Partial tertiary sewage	0	0.0	1	0.2
Final unchlorinated sewage	4	0.9	1	0.2
Final chlorinated sewage	3	0.7	3	0.7
Uv'd sewage	1	0.2	0	0.0
Sewage sludge	32	**7.7**	18	**4.7**
Activated sludge	1	0.2	0	0.0
Digester sludge	4	0.9	0	0.0
Chlorinated sludge	8	1.9	9	2.3
Untreated wastewater effluent	16	3.8	15	3.9
Partially treated wastewater effluent	0	0.0	2	0.5
Treated wastewater effluent	2	0.4	6	1.5
Untreated wastewater backwash	3	0.7	2	0.5
Chlorinated wastewater backwash	1	0.2	1	0.2
Storm water	1	0.2	0	0.0
Total Spills	414		380	

The graph, illustrated in Figure 6.3 and Appendix 6.15, indicates a clear spike in both 2003 and 2004, which represents the high frequency of spills involving raw sewage. Raw sewage spill events occurred in Ontario more often than all other spills put together representing 51.7% of the total spills in 2003, and 61.6% of the total spill incidents in 2004. Primary, chlorinated sewage was the second most frequent type of contaminant spilled in both years studied, with 78 spills in 2003 and 39 spills in 2004. The third highest peak found on the graph in Appendix 6.15 (Figure 6.3), is representative of failures resulting in the release of sewage sludge into the environment. The percentages of accidental sewage sludge discharge events, in 2003 and 2004, were found to be 7.7% and 4.7%, respectively. These findings show that sewage, at various incomplete levels of treatment, is the most frequent contaminant released into the environment via spill events. The high prevalence of disease-causing organisms, as described in preceding chapters, found in human sewage waste presents an immense danger to watersheds in areas susceptible to such spill events.

Figure 6.3: Graph of Types and Quantity of Contaminant Spills in 2003 and 2004



A somewhat surprising observation found in this data was the significantly low number of manure spills reported to the SAC annually. The 2001 Census report determined that there are approximately 59,728 agricultural farms within the province of Ontario, comprising 5,466,233 hectares of land. The same Census found that manure was applied to 2,721,289 hectares of land in the year 2000, which was later acknowledged to be under-reported (Statistics Canada, 2001). Given the extensive use of manure in agriculture, it is unexpected that in 2003 and 2004 only 10 and 15 manure spills, successively, were reported to the Ontario government. Therefore, it would reasonably be assumed that not all manure spill events are being reported properly. In recognition of past events and the current assumption of underreporting of agricultural spills, it seems that the overall risk to source watersheds from manure may be substantially underestimated. The findings of this analysis also raise questions pertaining to the accuracy in the quantity and frequency of all contaminant spills, including manure, being reported to the Ontario government.

6.2.3 Analysis of the Sources Responsible for Spill Events

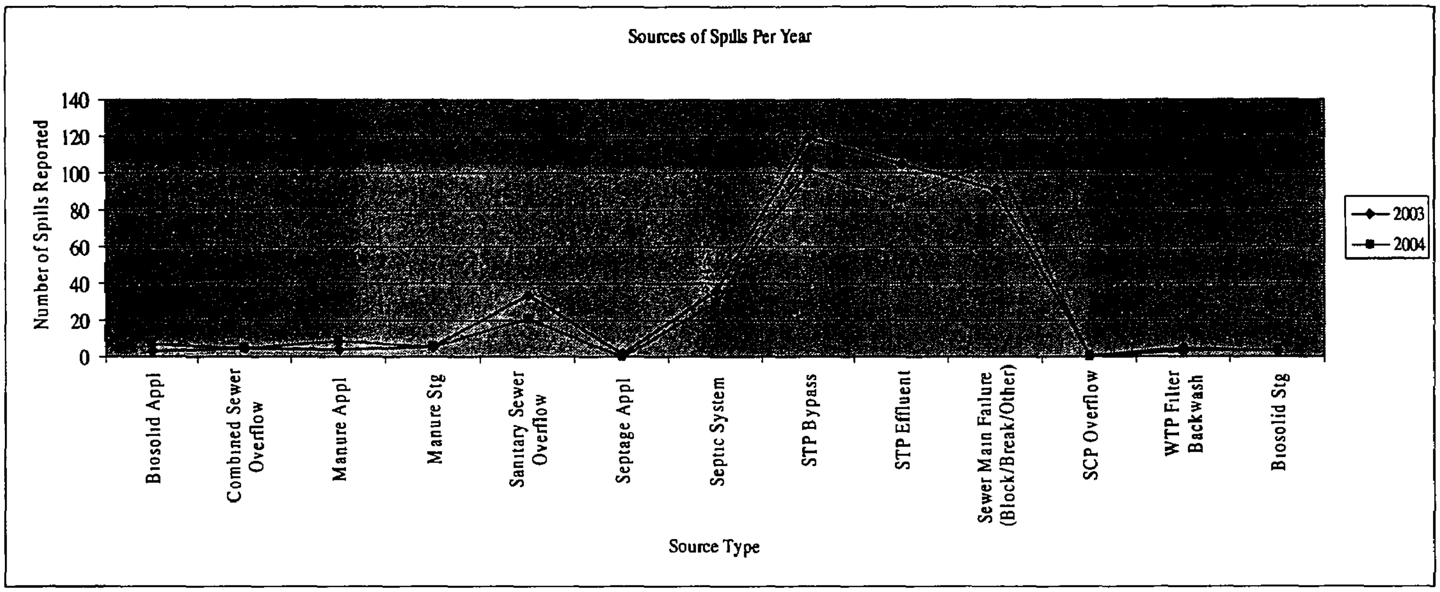
Distinguishing the location of an operation failure, or the source of a spill, is needed when assessing the risk of source watersheds to certain practices. The frequency of system failures associated with watershed-impacting operations can be used to determine the level of threat posed by such operations to source water resources. Using the data from the SAC, the sources of spills and their occurrence rates were tabulated and summarized in Table 6.6.

Table 6.6: Sources of Contaminant Spills in 2003 and 2004

Source Type	**2003**	**% of Total Spills**	**2004**	**% of Total Spills**
Biosolid Application Failure	3	0.7	7	1.8
Combined Sewer Overflow	5	1.2	5	1.3
Manure Application Failure	4	0.9	9	2.3
Manure Storage Failure	6	1.4	6	1.5
Sanitary Sewer Overflow	34	8.2	21	5.5
Septage Application Failure	2	0.4	0	0.0
Septic System Failure	36	8.7	30	7.8
Sewage Treatment Plant (STP) Bypass	**119**	**28.7**	102	26.8
Sewage Treatment Plant (STP) Effluent	105	25 3	86	22.6
Sewer System Failure (Block/Break/Other)	91	21.9	**107**	**28.1**
Stormwater Collection Pond (SCP) Overflow	1	0.2	0	0.0
Water Treatment Plant (WTP) Filter Backwash	5	1.2	3	0.7
Biosolid Storage Failure	3	0.7	4	1.0
Total	**414**		**380**	

The results of this analysis, displayed graphically in Figure 6.4, confer a range of spill sources responsible for discharging contaminants into the environment.

Figure 6.4: Graph of the Sources and Quantity of Contaminant Spills in 2003 and 2004



In 2003, 119 sewage treatment plant bypasses occurred throughout Ontario, representing the majority (28.7%) of contaminant spills. Following sewage treatment plant bypass events, the contaminant sources contributing to high occurrences of spills were sewage treatment plant effluent and sewer system failures, at 25.4% and 21.9%, respectively. In 2004, sewage treatment plant bypasses occurred less often (resulting in 102 spill events) and were found to be the second-most common source of contaminant spills. The top contaminant source in 2004, contributing to 28.2% of total spills, was sewer system failure. In third place, 22.6% of spills were from sewage treatment plant effluent. For reasons discussed earlier, the position of manure application and storage spills is unknown.

This information depicts that sewage treatment plants and sewer systems present a significant threat to source watersheds given their susceptibility to failure, although, these are not the only significant threats. Therefore, water sources in the vicinity of sewage treatment plants and sewer systems are at the greatest risk of pathogen contamination and should have the highest degree of protection.

6.2.4 Assessment of the Causes of Failure

Understanding the causes of failure can aid in determining the level of susceptibility of various operations to different kinds of failure. Knowing these causes is also essential for the development of failure prevention and mitigation techniques which should be included in source water protection programs. An analysis of the SAC spills data showed that there are several reasons why failure events occur, specifically related to source water impacting systems. There were 9 categories of causes found to contribute to spills. These categories include:

- Equipment failure;
- Operator error;
- Power failure;
- Adverse weather conditions;
- Fire;
- Vandalism;
- Electrical failure;
- Unknown reasons;
- and other random events.

These causes, along with their corresponding occurrence rates are summarized in Table 6.7.

Table 6.7: Causes of Spills Reported in 2003 and 2004

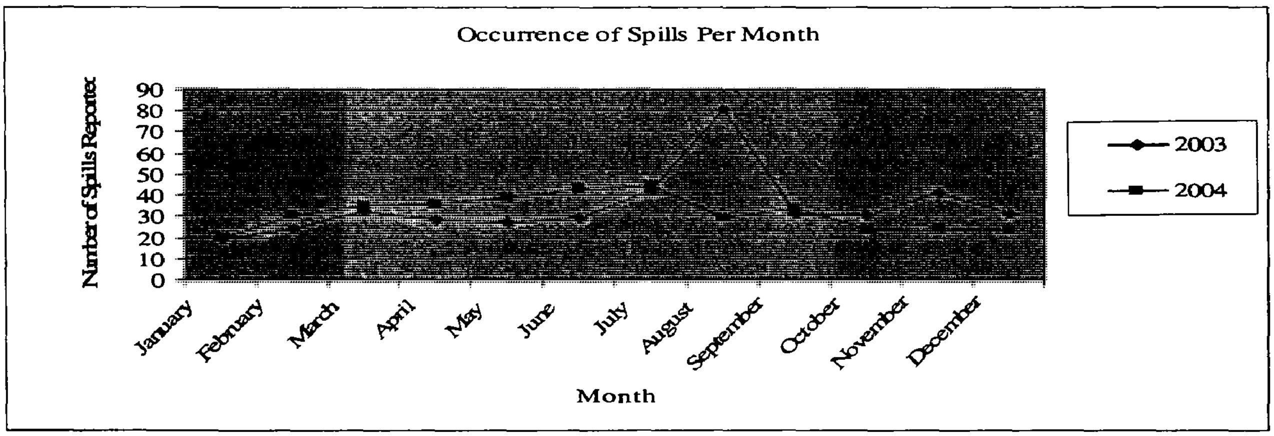
Cause of Spills	Number of Spills			
	2003	% of Total Spills	2004	% of Total Spills
Equipment Failure	**202**	**48.7**	**224**	**58.9**
Power Failure	**103**	**24.8**	35	9.2
Operator Error	44	10.6	**59**	**15.5**
Adverse Weather	35	8.4	40	10.5
Unknown	23	5.5	14	3.6
Other	5	1.2	2	0.5
Electrical Failure	2	0.4	1	0.2
Vandalism	2	0.4	4	1.0
Fire	2	0.4	1	0.2
Total	**414**		**380**	

The most common causes of failure leading to spills in 2003 were equipment failure (48.8%), power failure (24.9%), operator error (10.6%), and adverse weather conditions (8.5%). In 2004, equipment failure remained the most frequent cause for spills, but rose to an occurrence rate of 58.9%. The incidence of operator error and adverse weather conditions resulting in spills also rose in 2004 to 15.5% and 10.5%, respectively. However, given that these spills are self-reported, the accuracy of the number of spills due to operator error is questionable. An interesting observation was made in regard to the spills resulting from power failure. The number of power failure events responsible for spills in 2004 was equal to approximately 9% of the total spills that year, dropping tremendously from 24.9% in 2003. A deeper look into the seasonal trends associated with contaminant spills, seen in Table 6.4 and Figure 6.4, depicts that in August 2003, there was a sharp increase in the number of spill events.

Table 6.4: Summary of Spills Reported Monthly in 2003 and 2004

Year	**Month**												**Total Spills**
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
2003	19	24	32	28	27	29	**42**	**80**	31	30	**41**	31	414
2004	20	30	35	36	**39**	**43**	**44**	29	34	23	24	23	380

Figure 6.4: Graph of the Occurrences of Spills Reported Monthly in 2003 and 2004



Coincidently, at the same time, specifically on August 14, 2003, the largest power outage, 'black out', in decades swept across the province of Ontario. This clearly conveys the gross negative impacts of power outages on the efficiency of water utilization systems and the surrounding environment.

The spills report provided by the SAC was also useful in identifying the causes of failure most frequently associated with the sources of spills outlined in the previous section. This information, summarized in Appendices 6.16 and 6.17, showed that almost all sources of spills are affected by equipment failure, except for failures related to the storage of biosolids and stormwater infiltration ponds which were the result of operator error and weather, respectively. In 2003, equipment failure was found to be the leading cause of sanitary sewer overflow, septic system failure, sewage treatment plant effluent, and sewer system failure, which grew to include biosolids application and sewage treatment bypass in 2004. In 2003, operator error was most prevalently associated with sewer system spills and remained the same in the following year. As mentioned previously, there was an increase in power failure events in 2003, of which the majority resulted in sewage treatment plant bypasses. Although the occurrence rate of power failures diminished in 2004, the bulk of these events continued to correlate with bypasses of sewage treatment facilities. In regard to adverse weather conditions, these situations principally caused contaminant spills of sewage treatment plant effluent. The remaining causes of failure had minimal impacts on sources of spills, and consequently did not result in observable annual trends.

This analysis of the association between causes of failure and sources of spills indicated that equipment failure was the primary cause of contaminant spills. This should clearly indicate to the relevant authorities, especially those involved with sewer systems, the need to ensure the proper design and installation of equipment, and the importance of regular maintenance practices, back-up capabilities and contingency procedures in order to reduce and mitigate the potential for equipment malfunction (such as a chlorinator break down, which was a factor in the Walkerton outbreak). The high occurrence rate of operator error should also stress the need for sufficient training of equipment operators with specific emergency response procedures in place in case an accident occurs. In addition, this study has identified the critical need to have back-up generators on-site for all source water impacting operations. Back-up generators are essential in power failure events to ensure the efficient operation of mechanical systems.

6.2.5 Seasonal Trends Associated with the Occurrence of Spills

Weather conditions play an important role in the occurrence of spills. As described in the previous section, adverse weather conditions were responsible for 8.5% of spills in 2003 and 10.5% in 2004. Adverse weather conditions were found in the SAC data to include periods of heavy rainfall, strong winds, lightning, thunderstorms, freezing temperatures, frost and excessive snow melt. Severe weather conditions have the ability to cause tank and system overflows, create power outages, and result in cracks and breaks in pipes, valves, and other equipment. The effects of these damaging weather events were found, and displayed in Appendices 6.16 and 6.17, to have the most impact on sewage treatment plants, resulting in the premature release of effluent without completing the treatment process. The proportion of sewage treatment plant effluent spills, due to extreme weather conditions, was found to be 34.3% in 2003, compared to 36.6% in 2004. Sewage treatment facility bypasses were also frequently found due to adverse weather conditions, contributing to 22.9% of weather related spills in 2003 and 29.3% in 2004.

The seasons, primarily winter, spring, summer and fall, can often dictate the kinds of weather conditions expected in a region. Of course, the actual weather experienced may vary to a great extent from year to year. Given the proven association between weather events and the occurrence of spills, the SAC data were used to evaluate whether a seasonal trend exists in relation to the incidence of spills. Accordingly, Table 6.4 summarizes the seasonal (monthly) occurrence of spills for both 2003 and 2004. The seasonal variations, shown in Figure 6.4, reveal a definite peak in August of 2003, which was determined in Section 6.2.4 to be the result of a province-wide blackout within that timeframe. The following year, the number of spills reported in August dropped by 11.7%.

This study would also be expected to exhibit increases in the number of spill events during the spring months. This expectation is based on the large amount of water flowing off the land, into waterways and treatment facilities, during springtime when precipitation and snow melt is highest. This pattern was evident in 2004, with the highest number of spills occurring between March and July. However, this trend was not observed the previous year when July and August had the greatest number of spill occurrences, followed by the autumn months of September, October and November.

A conclusive determination of the relationship between spill events and seasonal occurrence can not be established with only two years of data. A longer time series analysis is needed in order to derive more reliable conclusions.

6.3 Failure Estimates Using Ontario SAC Spills Data: Summary

Strict standards and requirements enforced on source water impacting operations do not guarantee the protection of water resources from pathogen contamination. "Regardless of how well operated a drinking water system may be, unexpected incidents may occur" (F/P/T

Committee on Drinking Water and the CCME, 2002, p.9). The spills data provided by the Spills Action Center indicate that the existence of failure, contributing to spills of contaminants into the environment, certainly is not insignificant. On the contrary, failure is endemic among agricultural, industrial and municipal water utilization operations, and is thus a significant direct threat to source watersheds.

The spills data showed that sewer systems and sewage treatment facilities have the greatest probability of failure leading to the discharge of raw sewage into the environment. However, this finding may not be accurate given the suggestive evidence of significant underreporting of spills to the SAC, especially agricultural manure spills. Although geographical investigations, conducted as part of this study, did not find a correlation between population density and the occurrence of spills, there did seem to be a relationship between the sources of failure and population size. More specifically, it was determined that while larger communities are more susceptible to sewer system failures, smaller regions are prone to failure impacts from sewage treatment plants. In addition, this analysis proved that equipment failure was the primary cause of spills, while power failures, operator errors and adverse weather conditions also contributed tremendously to contaminant spills. Therefore, the health of source watersheds is significantly threatened by a substantial failure probability of water systems with inadequately designed and installed equipment, irregular maintenance practices, improperly trained operators, and by water facilities not equipped with back-up generators. Overall, the Spills Action Center data provided some insight into the nature and frequency of failure events related to watershed impacting operations throughout the province of Ontario. However, inconsistencies in the information suggest a need for further studies to look at spills data over an extended range of time in order to obtain greater confidence in the accuracy of conclusions.

Failure probability analysis was not acknowledged and recommended in the Technical Experts Committee's Report to the Minister (2004). However, given the high potential for such events to occur, some measure of the probability of failures must be included in the risk identification and assessment steps for source water protection planning.

Chapter Seven: Conclusion

7.1 Concluding Remarks

The cross-jurisdictional examination of policies, regulations and strategies, aimed at protecting drinking water and source water resources, established that source water protection laws are at an early stage of development among well-developed countries. Consequently, no attempt to grasp the full meaning of significance, in relation to threats to source watersheds, has been made outside of Ontario. The sole attempt to determine this important concept was developed by the Technical Experts Committee (TEC) of the Ontario Ministry of the Environment. However, this definition was only suggested by the TEC in hopes that it will be incorporated into the future *Drinking Water Source Protection Act,* which was proposed by the Ontario government in 2004. In the context of risks to source water, the determination of significance has been proven in this study to involve multiple factors including the characteristics of pathogenic microorganisms, the sources of pathogen contaminants in the environment, and the failure probability of source water impacting operations. This study has also identified that 'significance' is a qualitative determination of risk. However, if the degree of significance is to be determined, quantitative assessments of risk are suggested.

This study has shown that substantial scientific research has been focused on waterborne pathogens. These research findings prove that the pathogenic species *E.coli O157:H7*, *Salmonella*, *Giardia lamblia*, and *Cryptosporidium parvum* present, with certainty, a tremendous risk to source water quality and public health. Qualitatively, all four of these pathogens are judged to represent a significant threat to source watersheds given their size, survival characteristics, ability to resist environmental conditions, low infectious doses, and virulent nature. The quantitative significance of these microorganisms is dependant on their sources and failure probabilities of source water impacting systems.

The analysis conducted to assess the sources of pathogenic threats to source watersheds determined that, on a qualitative basis, storage and application of biosolids, septage and manure, sanitary sewage and septic system discharges, drinking water treatment backwash, and stormwater infiltration are all sources of critical pathogens in the environment and are, therefore, significant direct threats to source watersheds. The degree of significance affiliated with each of these pathogen sources requires an analysis of the frequency of the practice around a watershed, the potential amount and variety of pathogens which may be released due to such a practice and the legal parameters and requirements which confine each practice. Additionally, in order to accurately determine the quantitative significance of pathogen sources, failure probabilities of the systems associated with each pathogen source must be assessed.

While there is ample data focused on the sources of pathogen contamination, there has been insufficient research conducted into the occurrence of failing systems with source water impacts. The information collected from the Spills Action Center spills database, clearly indicated that the existence of failure, contributing to spills of contaminants into the environment, is a substantial, non-zero probability. In fact, this non-zero probability is high among agricultural, industrial and municipal water utilization operations, and is thus, qualitatively, a significant direct threat to source watersheds. Unfortunately, the information derived from this data set contained a considerable amount of uncertainty due to evident underreporting of spills, and the short time-frame used in the analysis of spills. A better understanding of failure is crucial if the characteristics of significant threats to drinking water resources are to be fully established.

The characterization of significant direct threats to source water is essentially a question of risk to environmental and public health, and must be assessed with precaution. Given the lack of scientific certainty about failure probabilities, the use of the Precautionary Principle is imperative when identifying significant direct threats to source watersheds. However, the consequences of employing this principle (such as the exclusion of land uses from source water protection areas) would be significant to many stakeholders. Therefore, as an alternative, it is recommended that in the development of source water protection legislation, and more specifically, the *Drinking Water Source Protection Act*, regulators must set minimum levels of significant risk. These minimum standards will allow local watershed authorities to determine acceptable levels of risk, so that the watershed can be managed appropriately.

Overall, the recommendations suggested given the findings of this study include:

- A better understanding of failure is crucial if the characteristics of significant threats to drinking water resources are to be fully established.
- Source water protection planning and management should be based on the Precautionary Principle when the risk of a significant threat to source water cannot be estimated.

- Given the lack of scientific certainty about failure probabilities, the use of the Precautionary Principle is imperative when identifying significant direct threats to source watersheds. However, the consequences of employing this principle would be costly to many stakeholders.
- Therefore, as an alternative, it is recommended that regulators, especially in the development of the *Drinking Water Source Protection Act*, set minimum levels of significant risk to allow local watershed authorities to determine acceptable levels of risk, in order for the watershed to be managed appropriately.

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Appendices

Appendix 2.1: Various Approaches Used to Determine Acceptable Risk

Approach	Description	Advantages	Difficulties
Predefined Probability Approach	Refers to known definitions of acceptable risk such as the one in a million gold standard and other standards developed by the USEPA		The outcome of these methods for determining acceptable risk is inconsistent throughout society and does not consider all factors important to stakeholders.
Currently Tolerate Approach	Any risk that is currently tolerated is considered to be acceptable	Only of used when incorporated with informed choice.	Problematic because it assumes that accepted risk is synonymous with acceptable risk. In reality, there is a difference between the two.
Disease Burden Approach	Considers health risk in terms of the total disease burden of a community and defines acceptability in terms of falling below an arbitrarily defined level.		It is difficult to attribute cases of illness to a specific cause when there is more than one route of transmission; There is known under-reporting of gastroenteritis in countries with surveillance systems; It is difficult to extrapolate illness data to countries with limited surveillance systems experiencing very different sanitation conditioning; the current burden of disease attributed to a single factor may not be a good indicator of the potential reductions available from improving water quality.
Economic Approach	A risk is acceptable if the economic savings arising out of action to reduce risk outweighs the cost of such action. It is a simple cost-benefit analysis approach.	Economic imperatives must be considered when determining acceptable risks.	The exact amount of illness may not be known with any certainty, especially if much illness is related to specific outbreaks; Even if the amount of illness is known, the costs of that illness may be difficult to identify; Even if the costs are identifiable, the cost of that illness are borne by different groups in society; Financial costs are not the only and probably not the main reason for change;
Public Approach	Based on what is acceptable to the general public. Therefore, a risk is acceptable when it is acceptable to the general public.	Public opinion is able to play a central role in the risk decision-making process.	In order for this approach to work, all sections of the community must have full access to all information required on levels of risk and have the skills to interpret that information; There must be an effective means of reaching consensus within the community and canvassing that consensus opinion which is unlikely; Individuals perceive the nature of risk in different ways; People's judgments are frequently subject to bias; Different priorities exist amongst the general public
Political Resolution (Bargaining) Approach	The definition of acceptable will not be concurred by all stakeholders. Therefore, resolving risk issues must become a political process. Involves bargaining.	Avoids the uncertainties of science and expert analysis.	Instead of the best solution for society, one gets the solution that is acceptable to most/all stakeholders, known as satisficing. As a result, not all relevant stakeholders may be considered in defining acceptable criteria; All stakeholders will have differing levels of power and interest in the bargaining process; Socially excluded groups in society are excluded; The powerful groups include industry, the wealthy, and the educated who all have greater access to information and the resources to prepare their arguments.

* Source: Hunter and Fewtrell (2001)

Appendix 3.1: Summary of Jurisdictional Legislation for Drinking Water and Source Water Protection

Jurisdiction	Legislative Documents related to Drinking Water and Source Water Protection	Key Environmental Authority	Does this Document Contain Water Quality Standards?	Is Legislation Legally Binding or Voluntary?	Are Microbes (Pathogens) Addressed?	Is an Acceptable Level of Risk Addressed?*
Canada	Guidelines for Canadian Drinking Water Quality, 2004	The F/P/T DWS[1]	Yes	Voluntary	Yes, primarily concerned with E.coli and total coli forms. Does address some protozoa and viruses.	No, but a proposed Maximum Acceptable Concentration value is used for microorganisms.
	From Source to Tap: Guidance on the Multi-Barrier Approach to Safe Drinking Water, 2004	CCME[2] and the F/P/T DWS	No, provides detailed information for owners and operators on how to integrate the multi-barrier approach.	Voluntary	Yes	No
	From Source to Tap: The Multi-Barrier Approach to Safe Drinking Water, 2002	The F/P/T DWS	No, outlines the elements of the multi-barrier approach.	Voluntary	Yes, recognizes pathogens as a risk to drinking water quality.	No

	Guidance for Safe Drinking Water in Canada: From Intake to Tap, 2001	The F/P/T DWS	No, document stresses the need for a multi-barrier approach to safe drinking water.	Voluntary	Yes, recognizes the need to protect drinking water from pathogens.	No
	Public Health Initiatives Related to Drinking Water Quality, 2003	Health Canada	No, reviews Canadian initiatives in order to provide public awareness.	Voluntary	Not directly	No
	Canadian Environmental Protection Act, 1999, c.33	Government of Canada	No, first piece of legislation honoring pollution prevention and environmental protection.	Legally Binding	No (only chemical, toxic, contaminants addressed)	No
	Federal Water Policy, 1987	Environment Canada	No, it is a statement of the government's goals for the nation's freshwater resources.	Voluntary	No	No
British Columbia	*Groundwater Protection Regulation, 2004*	B.C. Ministry of Water, Land and Air Protection	Yes	Legally Binding	No	No
	Drinking Water Protection Act, 2003	Government of British Columbia	Yes, for potable water only	Legally Binding	Yes, for fecal coliform (*E.coli*) and Total Coliform bacteria.	No

	Action Plan for Safe Drinking Water in British Columbia, 2002	B.C. Ministry of Planning and Ministry of Health Services	No	Voluntary	No	No
	Drinking Water Protection Act, 2001	Government of British Columbia	No, and regulations are needed to enforce this Act	Legally Binding	No	No
	Protecting Drinking Water Sources, 1999	Auditor General of British Columbia	No	Voluntary	Yes	No
Ontario	The Technical Experts Committee Report to the Minister of the Environment, 2004	Technical Experts Committee	Proposes Standards to be included in the new Source Water Protection Act.	Voluntary	Yes, concerned with *E.coli*, *enterococci*, coliphage, and *Cryptosporidium*	Yes, the first and only definition of a 'significant direct threat' is **proposed**.
	White Paper on Watershed-Based Source Water Protection Planning, 2004	Ontario Ministry of the Environment	No, informs Ontarians of the proposed source water protection program and other Ministry initiatives.	Voluntary, it is an information document.	No	No

	Protecting Ontario's Drinking Water: Towards a Watershed-Based Source Protection Planning Framework, 2003	Advisory Committee on Watershed-Based Source Protection Planning	No	Voluntary	Yes	No
	Safe Drinking Water Act, 2002, c.32	Government of Ontario	No, deals with treatment and distribution of drinking water	Legally Binding	Yes, only briefly	No
	The Nutrient Management Act, 2002, c.4	Government of Ontario	Yes, standards are present under *Ontario Regulation 267/03*	Legally Binding	Yes, E.coli	No
	Part Two: A Strategy for Safe Drinking Water, 2002	Justice Dennis O'Connor	No, presents 93 recommendations	Voluntary	Yes	No, but 5th recommendation suggests determining a 'significant direct threat' to source water.
	The Report of the Walkerton Inquiry, Part One: The Events of May 2000 and Related Issues, 2002	Justice Dennis O'Connor	No, presents 28 recommendations	Voluntary	Yes	No

	Ontario Water Resources Act, 1990, c.0.4	Government of Ontario	No, legislation which governs municipal water works.	Legally Binding	No	No
USA	Consider the Source: A Pocket Guide to Protecting Your Drinking Water	US EPA[3]	No	Voluntary, this document is guidance paper to provide public information.	Yes	No
	The Proposed Ground Water Rule, 2000	US EPA	No	Not at present, but will be in the future	Yes	No
	State Source Water Assessment and Protection Programs Guidance	US EPA	No	Legally Binding	Yes	No
	The Safe Water Drinking Act (1974) (amended 1986 and 1996)	US EPA	No (This piece of legislation authorizes the USEPA to set national drinking water standards)	Legally Binding	Yes	No
	The National Primary Drinking Water Regulations (revised 2002)	US EPA	Yes	Yes	Yes	Yes, denotes Maximum Contaminant Levels allowed in drinking water.

	The National Secondary Drinking Water Regulations	US EPA	Yes	Voluntary by State	No	No
	The National Environmental Policy Act 1969 (NEPA)	The United States Department of Energy	No	Legally Binding	No	No, but was first attempt to use the word significant in environmental legislation.
Florida	*Florida's Source Water Submittal to EPA, 1999*	Florida Department of Environmental Protection	Yes	Legally Binding	Yes, those regulated under the Primary Drinking Water Regulations and Cryptosporidium.	No
	Florida's Wellhead Protection Program, 1998	Florida Dept. of Environmental Protection	No	Legally Binding	No	No
	Florida's Wellhead Protection Rule (c. 62-521), 1995	Florida Dept. of Environmental Protection	Yes, defines a 'wellhead protection area' as an area consisting of a 500 ft radius around potable water well.	Legally Binding	No	No
New Jersey	*New Jersey Safe Drinking Water Act (Assembly Bill* 280), 1983 amendments	New Jersey Department of Environmental Protection	Yes	Legally Binding	No	No

	The New Jersey Source Water Assessment Program Plan, 1999	New Jersey Dept. of Environmental Protection	Yes	Legally Binding	Yes, those set out in the *Federal Safe Drinking Water Act, 1996* plus Giardia and Cryptosporidium	No
	Guidelines for Delineation of Wellhead Protection Areas in New Jersey, 2003	New Jersey Dept. of Environmental Protection and the New Jersey Geological Survey	Yes	Legally Binding under the 1986 Federal *Safe Drinking Water Act Amendments*	No	No
Europe	*The EU Water Framework Directive* (2000/60/EC)	The European Commission	No	Legally binding	No	No
	The Council Directive 98/83/EC (1998)	The European Commission	Yes, at consumer's tap	Legally binding	Yes, *E.coli* and enterococci	No
The United Kingdom	*The Water Supply (Water Quality) Regulations, 2000*	The United Kingdom Environment Agency	Yes	Legally Binding	Yes, *E.coli*, enterococci, and cryptosporidium	No, but does define 'significant risk from cryptosporidium'
Northern Ireland	*Water Supply (Water Quality) Regulations (N.Ireland)* (2002)	Northern Ireland - Dept. of the Environment	Yes, only at point of use – consumer's tap.	Legally binding	Yes	No, not for raw water

	Policy and Practice for the Protection of Groundwater in Northern Ireland (2001)	Environment and Heritage Service – Dept. of the Environment	Yes, provides TOT values in Source Protection Zones	Voluntary (Proposal to be implemented by 2010)	Yes, Source Protection Zone 1 is intended to protect against microbial pollutants.	No
Scotland	*The Cryptosporidium (Scottish Water) Directions*, 2003	The Drinking Water Quality Regulator of Scotland (DWQR)	No	Legally binding as of 2004	Yes, Cryptosporidium only	Yes, a grading system is used for surface and ground water as a means of risk assessment for cryptosporidium
	The Water Industry (Scotland) Act, 2002	The Scottish Executive	No	Legally binding	No	No
	The Water Supply (Water Quality) (Scotland) Regulations, 2001	The Scottish Executive	Yes, only at point of use	Legally binding	Yes	No
New Zealand	*Background Paper: Proposed National Environmental Standard for Raw Drinking-Water Sources* (2004)	New Zealand Ministry of the Environment	No	Voluntary (Proposed)	Yes (Microbial contaminants contribute to Catchment Risk Category)	Yes (A 4-Step process is suggested in this Catchment Risk Assessment Framework.

	Drinking Water Standards for New Zealand, 2000	New Zealand Ministry of Health	Yes	Voluntary	Yes	Yes, uses the term Maximum Acceptable Value but does not apply to first barrier (raw water).
	Health Act, 1956	New Zealand Ministry of Health	No (Main purpose is to determine governing authorities)	Legally Binding	No	No
Australia	*Water Quality Protection Note: Land Use Capability in Public Drinking Water Source Areas*, 2004	Western Australia – Dept. of Environment	No	Voluntary	No	Yes, 3 categories are defined in relation to acceptability of land uses and activities within catchments.

	Discussion Paper: Reserving and Protecting Water Resources for Future Use In Western Australia, 2003	Western Australia – Dept. of Environment	No	Voluntary (Provides advise to minimize the potential for contamination of future drinking water source areas.	No	No
	National Water Quality Management Strategy: Australian Drinking water Guidelines 1996 (amended 2001)	NHMRC[4] and ARMCANZ[5]	Yes, though only for drinking water at point of use.	Voluntary (They represent a framework for identifying acceptable water quality through community consultation)	Yes	No
	The Sydney Water Catchment Management Act, 1998	New South Wales – Dept. of Environment and Conservation	No (Main purpose was for the establishment of the Sydney Catchment Authority)	Voluntary (Provides advise concerning the development of CMCs[6] and CMTs[7])	No	No
	Environment Protection Act, 1997	Australian Capital Territory (ACT)	Yes (not directly concerned with source water standards)	Legally Binding	Yes	No

	Environmental Protection Act (Water Quality) Policy (1997) (amended 2003)	Queensland Parliamentary Council	Yes (not directly concerned with source water standards)	Legally Binding	Yes (E.coli)	No (Though acceptable value for 'potable water' is 0.0 faecal coliforms per 100 mL)
	National Water Quality Management Strategy: Guidelines for Groundwater Protection in Australia (1995) – Also applies to New Zealand	ANZECC[8]	No (Provides a framework for the protection of groundwater contamination)	Voluntary	No	No, however, minimum protection zones in a catchment area are proposed.

Note:
1. The Federal-Provincial-Territorial Subcommittee on Drinking Water
2. The Canadian Council of Ministers of the Environment
3. The United States Environmental Protection Agency
4. The Agriculture and Resource Management Council of Australia and New Zealand the
5. The National Health and Medical Research Council
6. Catchment Management Committee
7. Catchment Management Trust
8. The Australian and New Zealand Environment and Conservation Council

Appendix 3.2: Groundwater Protection Measures in Wellhead Protection Areas

Requirements of Rule	Restrictions
62-521.400 (1) The Department shall require new installations to meet the following restrictions within a wellhead protection area.	(a) New domestic wastewater treatment facilities shall be provided with Class I reliability, and flow equalization. New wastewater ponds, basins, and similar facilities shall be lined or sealed to prevent measurable seepage. Unlined reclaimed water storage systems are allowed for reuse in some projects.
	(b) New reuse and land application projects shall be prohibited except for new projects permitted.
	(c) New domestic wastewater residuals land application sites shall be prohibited.
	(d) New discharges to ground water of industrial wastewater shall be prohibited except as provided below: 1. All non-contact cooling water discharges (without additives); and 2. Discharges specifically allowed within a wellhead protection area
	(e) New phosphogypsum stack systems are prohibited.
	(f) New Class I and Class III underground injection control wells are prohibited.
	(g) New Class V underground injection control wells are prohibited except as provided below: 1. Thermal exchange process wells (closed-loop without additives) for use at single family residences; and 2. Aquifer storage and recovery systems wells, where the injected fluid meets the applicable drinking water quality standards.
	(h) New solid waste disposal facilities are prohibited.
	(i) New generators of hazardous waste which excludes household hazardous waste.
	(j) New hazardous waste treatment, storage, disposal, and transfer facilities requiring permits are prohibited.
	(k) New aboveground and underground tankage of hazardous wastes is prohibited.
	(l) Underground storage tanks shall not be installed 90 days after the effective date of this rule. Replacement of an existing underground storage tank system, within the same excavation, or addition of new underground storage tanks at a facility with other such underground storage tanks is exempt from this provision, provided that the replacement or new underground storage tank system is installed with secondary containment.
	(m) Aboveground storage tanks shall not be installed 90 days after the effective date of this rule. Replacement or upgrading of an existing aboveground storage tank or addition of new aboveground storage tanks at a facility with other such aboveground storage tanks is exempt from this provision, provided that the replacement or new aboveground storage tank system meets the applicable provisions
	(n) Storage tanks which meet the auxiliary power provisions for operation of a potable water well and storage tanks for substances used for the treatment of potable water are exempt from the provisions of this rule.

	(o) Applicants should take note that to prevent the vertical migration of fluids, a water management district may require a construction permit for new water wells, which shall meet the applicable construction standards.
(2) Emergency equipment, including storage tanks, that is necessary to provide power to ensure a continuous supply on an emergency basis of public water supply, electrical power, sewer service, telephone service, or other essential services that are of a public benefit are exempt from the provisions of this chapter. This does not exempt these services from meeting other applicable Department rules.	
(3) Discharge to ground water from Department approved remedial corrective actions for contaminated sites located within wellhead protection areas shall not be subject to the discharge restrictions in this chapter.	
(4) Nothing herein supersedes more stringent setback or permitting requirements contained in other Department rules.	

Appendix 4.1: Summary of Characteristics of Common Pathogenic Microorganisms

CHARACTERISTICS OF COMMON PATHOGENIC MICROORGANISMS

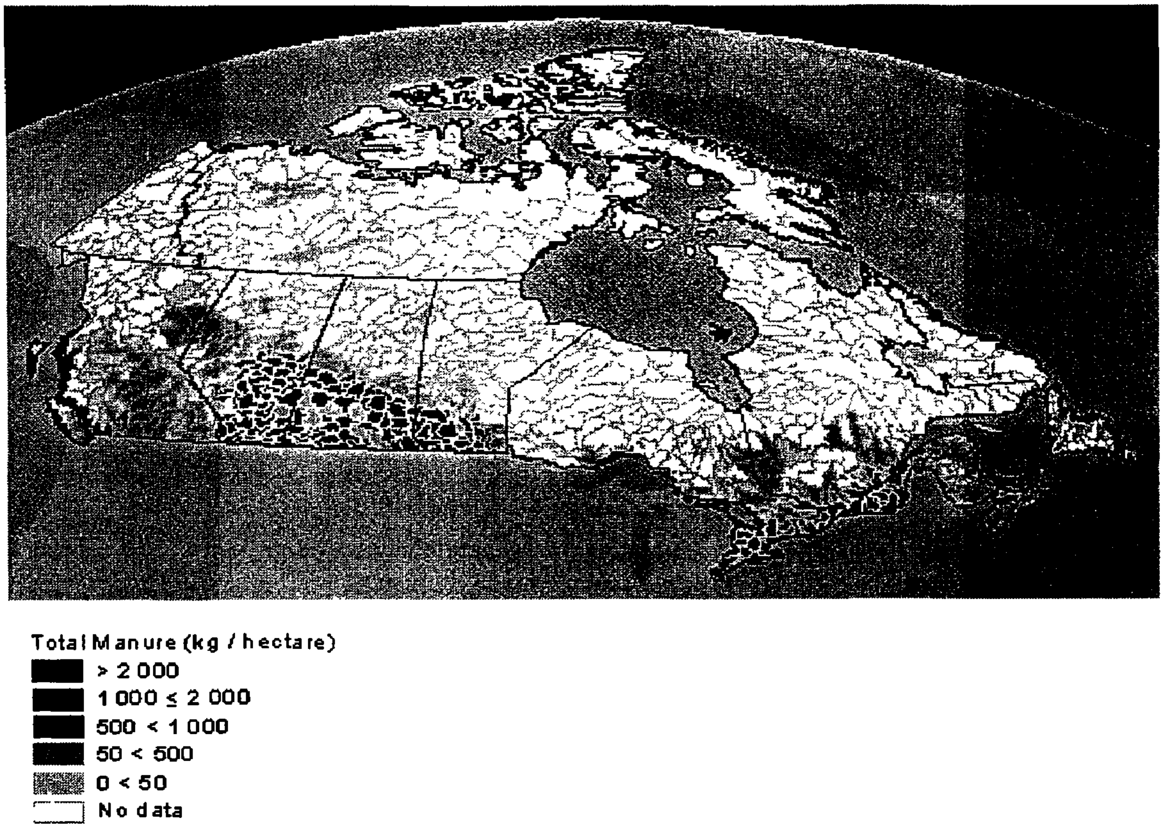
Pathogen	Sources of Infection	Related Diseases / Symptoms	Treatment Available	Survival Characteristics [1]			ID 50	Mortality Rate
				MEDIUM	TEMP	TIME		
Bacteria								
Escherichia coli O157:H7	Cattle are the primary reservoir for EHEC though humans can also be a carrier. Infection of EHEC may be the result of ingesting undercooked beef or contaminated water.	Watery diarrhea, abdominal cramps, 40% develop hemorrhagic colitis (bloody diarrhea), abdominal pain, 11% of those who develop hemorrhagic colitis will also develop hemolytic-uremic syndrome (HUS) (destruction of blood cells). Thrombotic Thrombocytopenic	Most persons with *E.coli O157:H7* infection recover without antibiotics within 5 to 10 days. Dialysis is required for 50% of patients with kidney damage caused by HUS or TTP. Blood transfusions may also be needed.	Water	frozen cold (5C) warm (30C)	> 300 days > 300 days 84 days	Low (10-100)	3-5% of HUS cases with intensive care are fatal. 50% of TTP cases are fatal.
				Soil	frozen cold (5C) warm (30C)	>300 days 100 days 2 days		
				Cattle Feces	frozen cold (5C) warm (30C)	>100 days >100 days 10 days		
				Slurry		10-100 days		
				Compost		7 days		
				Dry Surfaces		1 day		
Salmonella typhimurium and Salmonella enteritis	Food or water contaminated with animal or human feces.	Enteritis: nausea, vomiting, abdominal pain, diarrhea, fever, headache, chills - self limiting disease but may be life-threatening to infants and the elderly. Typhoid Fever: anorexia, lethargy, headache, cough, constipation	For patients with *Salmonella enteritis*, treatment with antibiotics has been proven ineffective in for reducing the duration and severity of the disease. Instead, patients should be kept hydrated and electrolytes should be replenished as needed.	Water	frozen cold (5C) warm (30C)	> 6 mos > 6 mos > 6 mos	High (10^6 - 10^7) because they are sensitive to stomach acid.	The mortality rate for patients with Salmonellosis is 2.5%. *Salmonella enteritis* is self-limiting and usually lasts about 5 days, but severe loss of fluids and electrolytes may be life-threatening in infants and
				Soil	frozen cold (5C) warm (30C)	> 12 wks 12-28 wks 4 wks		
				Cattle Feces	frozen cold (5C) warm (30C)	> 6 mos 12-28 wks 4 weeks		
				Slurry		13-75 days		
				Compost		7-14 days		
				Dry Surfaces		1-4 days		

								elderly patients. The mortality rate for patients who develop Typhoid Fever is 2-10%.
Protozoa								
Giardia lamblia	Surface water contaminated with human feces (treated and untreated Combined Sewer Overflow sewage)[3] or animal (commonly beaver) feces.	Giardiasis - results in severe diarrhea and weight loss. Most patients recover from acute Giardiasis but some develop chronic recurrent diarrhea which may be accompanied by headaches, lassitude, myalgia, and weight loss. Infection with *G.lamblia* may also	Treatment with antibiotics for 7 days usually relieves symptoms and cures the disease.	Water	frozen cold (5C) warm (30C)	< 1 day 11 wks 2 wks	Low (1 *G.lamblia* cyst is infectious)	Mortality rate is less than 0.1%. Giardiasis does not usually result in mortality except in situations of extreme dehydration.
				Soil	frozen cold (5C) warm (30C)	< 1 day 7 wks 2 wks		
				Cattle Feces	frozen cold (5C) warm (30C)	< 1 day 1 wk 1 wk		
				Slurry		1 yr		
				Compost		2 wks		
				Dry Surfaces		1 day		
Cryptosporidium parvum	Water contaminated with mammalian (especially human) feces. Significant sources are wastewater discharges and agricultural land runoff. [4]	Cryptosporidiosis: untreatable intestinal illness causing severe watery diarrhea. May persist for several days to a couple of weeks. Often accompanied by nausea, vomiting and fever. Can be fatal in immunocompromised patients (children and the elderly).	There is no adequate specific treatment for Cryptosporidiosis.	Water	frozen cold (5C) warm (30C)	> 1 yr > 1 yr 10 wks	ID_{50} of 10-100 oocysts.[4]	*C. parvum* can cause a life-threatening form of watery diarrhea in immunosuppressed patients.
				Soil	frozen cold (5C) warm (30C)	> 1 yr 8 wks 4 wks		
				Cattle Feces	frozen cold (5C) warm (30C)	> 1 yr 8 wks 4 wks		
				Slurry		> 1 yr		
				Compost		4 wks		
				Dry Surfaces		1 day		

Notes:

1. Survival Characteristics taken from Olson, M.E, 2001, p. 9.
2. Source: States et al. 1997.
3. Source: Godfree, A., and Farrell, J. 2005.
4. Source: Health Canada, 2004.

Appendix 5.1 - Estimated Total Manure Production by Provincial Region in 1996



* Source: Statistics Canada, 2005.

Appendix 5.2: Minimum Distance Separation (MDS) Between Permanent Storage Structures and Neighboring Land Uses

REGULATION	CRITERIA
Site Location: O. Reg. 267/03, 2. 83(2)	≥ 45 m from a drilled well with watertight casing.
	≥ 100 m from a municipal well.
	≥ 90 m from any other well.
	If storing manure or other prescribed materials*, at least 125 m from a single residence and 250 m from a residential area. However, if storing de-watered municipal sewage biosolids, then at least 200 m from a single residence and 450 m from a residential area.
Site Conditions: O. Reg. 267/03 s. 83(1)	Minimum depth of unconsolidated soil to bedrock, under the site and within 3 m of the side of the site, to be at least 0.3 m.
	Minimum depth of soil above the water table, under the site and within 3 m of the side of the site, to be at least 0.9 m.
	No storage allowed on soils with a rapid infiltration rate. A coarse-textured, gravely soil would be a typical example of an unsuitable location.
	The site must be located at an elevation above the 1-in-100-year flood line established by the municipality or local conservation authority.
	The site must not have a slope greater than 3%.
	There must be a flow path away from the storage site that is at least 50 m to the nearest surface water or tile inlets, and is located at least 0.3 m above bedrock.

* A "prescribed material" means either an agricultural source material or a non-agricultural source material excluding commercial fertilizer and compost. (O. Reg. 267/03, 2. 83(2)).

Appendix 5.3: Land Application Standards for Manure

Subject of Application Standard	Criteria of Regulation	Sub sub-section Criteria	Ontario Regulation
Application rates of liquid prescribed materials	42.1 No person shall apply liquid prescribed materials to land, within 150 metres from the top of the bank of surface water	1 (a) if the runoff potential for the land shown on the table shows that no application is allowed; (b) at a rate in excess of that determined under the table to subsection (5); or (c) if the field slope of the land is greater than 12%.	O. Reg. 267/03, s. 42 (1).
Wells and other land uses (set backs from wells)	(1) No person shall apply nutrients to land closer than 100 metres to a municipal well. (2) No person shall apply prescribed materials to land closer than 15 metres to a drilled well that has a depth of at least 15 metres and a watertight casing to a depth of at least six metres below ground level. (3) No person shall apply agricultural source materials to land closer than 30 metres to a well, other than a well described in subsection (1) or (2). (4) No person shall apply non-agricultural source materials to land closer than 90 metres to a well, other than a well described in subsection (1) or (2). (5) No person shall apply commercial fertilizer or compost to land closer than 3 metres to a water well that is not a municipal well.		O. Reg. 267/03, s. 43 (1-5).

Adjacent surface water (requirement for vegetated buffer zone)	44. (1) No person shall apply nutrients to a field that contains or is adjacent to surface water unless there is a vegetated buffer zone in the field that is adjacent to the surface water and that lies between the surface water and where the nutrients are applied. (2) Subsection (1) does not apply in relation to the application of nutrients to a field that is composed of organic soils. (3) No person shall apply nutrients within the vegetated buffer zone except for an amount of commercial fertilizer that is reasonable to establish or maintain the vegetation of the buffer zone. (5) A person may apply commercial fertilizers or agricultural source material within the 13 metres from the top of the nearest bank of the surface water if the application is done in accordance with this Regulation.	44. (5) (a) by injection or placement in a band below the soil surface; (b) so that the materials applied are incorporated within 24 hours of application; (c) to land covered with a living crop; or (d) to land with crop residue covering at least 30 per cent of the soil, as determined in accordance with the Nutrient Management Protocol.	O. Reg. 267/03, s. 44 (1-5).
Minimum depth to groundwater	46. No person shall apply prescribed materials to land unless there is at least 30 centimetres of unsaturated soil condition at the surface of the land at the time of application.		O. Reg. 267/03, s. 46.
Application during winter and other times when soil is snow covered or frozen (requirements for application of prescribed material)	48. (1) Subject to section 47, no person shall apply prescribed materials to land during the period beginning on December 1 of one year and ending on March 31 of the following year or at any other time when the soil of the land is snow-covered or frozen except in accordance with this section.		O. Reg. 447/03, s. 22.

Methods of Application (high trajectory)	49. (1) Despite section 40, whether or not this Regulation requires an operation to have a nutrient management plan, no person shall use a high trajectory irrigation gun capable of spraying liquid more than 10 metres to apply manure or non-agricultural source materials to land except if the material being applied is an aqueous solution or suspension containing more than 99 per cent water by weight.		O. Reg. 267/03, s. 49 (1).
Methods of Application (direct flow application systems)	50. (1) No person shall apply manure or non-agricultural source materials directly from a storage facility to land by a direct flow application system unless the system is operated in accordance with this section.		O. Reg. 267/03, s. 50 (1).

* Source: Nutrient Management Act (2002) Ontario Regulation 267/03.

Appendix 5.4: Types of Treatment Processes Commonly Used in Waste Water Treatment Facilities

Type of Sewage Treatment	**Process Description**
Primary Treatment	Involves the screening of wastewater influent to remove large biomasses, followed by sedimentation during which sand, gravel and other heavy materials settle out of the water. This process removes particles unable to dissolve in water but is not intended to remove toxic or hazardous contaminants (Kapitain, 1995).
Secondary Treatment	Treatment beyond settling solids, responsible for the removal of 85% of conventional pollutants (BOD and suspended solids) and maintains proper pH levels of the wastewater (LGEAN, 2005).
Tertiary Treatment	An advanced level of treatment used to remove pollutants such as nutrients, toxic compounds, increased organic matter and suspended solids. This process is accomplished through various physiochemical and biological methods. A final disinfection treatment can also be incorporated into this process to eliminate disease-causing microorganisms. Methods of disinfection may involve chlorine, ozone and/or ultraviolet light (Environment Canada, 2005).
Lagoons	In sewage lagoons, wastewater is treated by bacterial organisms at naturally occurring rates and is thus a very lengthy process. Once treated the effluent is either released to a waterway or allowed to infiltrate into the ground. The relatively simple and inexpensive operation of a sewage lagoon makes this treatment method ideal for small communities (Kapitain, 1995).
Communal Septic Systems	These systems are used primarily in smaller communities and consist of a single storage settling tank used to hold sewage while anaerobic bacteria decompose the settling solids (Kapitain, 1995). The effluent is released beneath the settling tank into the ground.

Appendix 5.5: Characteristics and Efficiency of Common Filtration Technologies

Filtration Technology	Characteristics	Pathogen Removal Efficiency
Conventional Filtration	Includes chemical coagulation, rapid mixing, and flocculation, followed by floc removal via sedimentation. Types of filter media include sand, mon-media, dual-media, and tri-media, combining sand, anthracite, and other media.	99% removal efficiency for viruses, and 97 to 99.9% removal efficiency for *Giardia lamblia*.
Direct Filtration	Has many effective variations, all of which include; a chemical coagulation step followed by rapid mixing and all exclude the use of an extra clarification step such as sedimentation prior to filtration. Filter media include dual or mixed media filters.	
Slow Sand Filtration	The top-most, biologically active layer of the filter removes suspended organic materials and microbials by biodegradation and other processes, rather than relying solely on simple filter straining or physio-chemical sorption. Advantages include low maintenance requirements and does not require backwashing.	
Diatomaceous Earth Filtration	Can be used to directly treat source water supplies with low turbidity or chemically coagulated, more turbid water sources. Treatment is supplemented by a continuous-body feed of diatomite and recycled filtered water.	
Manganese Greensand Filtration	Manganese greensand is commonly used to remove iron, manganese and sometimes arsenic from groundwater supplies. Greensand media is typically regenerated by a continuous feed of potassium permanganate and/or chlorine ahead of the filter. Process driven by pressure or vacuum.	
Membrane Filtration	There are four types of membrane filtration processes which make use of pressure-driven semi-permeable membrane filters. Each type uses filter membranes of different materials and pore sizes.	
Membrane Filtration: Reverse Osmosis	Treatment operates in a high-pressure mode, and is effective in removing salts. Pore size is roughly 0.0001 microns. Process produces the most wasted water (25% - 50% of feed), and additional disinfection is recommended.	Effective for removing cysts, bacteria and viruses.
Membrane Filtration: Nanofiltration	Operates in a medium pressure mode, and is effective in removing calcium and magnesium ions, organics and disinfection byproducts. Typical pore size is 0.001 microns. Additional disinfection measures are recommended.	Effective for removing cysts, bacteria and viruses.
Membrane Filtration: Ultrafiltration	Treatment involves a wide band of molecular weight cut-offs, and operates under low pressure. Removes dissolved organics and particulates. Additional disinfection recommended for absolute microbial removal. Typical pore size is 0.01 microns.	Effective for absolute removal of *Giardia* cysts and partial removal of bacteria and viruses.
Membrane Filtration: Microfiltration	Operates under low pressure and is effective at removing particulates. Pore size is typically 0.0001 microns. Additional disinfection methods recommended for microbial removal.	Effective for absolute removal of *Giardia* cysts and partial removal of bacteria and viruses.

*Source: Canadian Council of Ministers of the Environment, 2004.

Appendix 5.6: Common Stormwater Management Practices

Stormwater Management Practice	Description	Advantages / Disadvantages
Soakaway Pits	Stone-filled (golf-ball size) excavations where stormwater runoff collects and then enters the ground.	Beneficial for single lots.
Infiltration Trenches	Also stone-filled (golf-ball size) excavations where stormwater runoff collects and then enters the ground.	Beneficial for receiving water from several lots.
Grassed Swales	Typically shallow depressions several metres wide that hold stormwater. The vegetation slows and filters. Dams may be incorporated at intervals along swales to promote infiltration and settling of contaminants.	Vegetation allows for slow filtration of stormwater into the soil.
Pervious Pipe Systems	Incorporates a perforated pipe into a bed of golf ball sized stone. The perforations allow water to flow out of the pipe as it is directed downstream. The water is stored in the stone medium until it can infiltrate into the surrounding soils.	In the right soils, this kind of system can allow the storage medium to empty within a reasonably short time.
Dry Ponds	A detention basin designed to temporarily store collected stromwater runoff and release it at a controlled rate through an outlet. They may have a deep pool of water in the sediment to reduce scour and resuspension of sediment, but do not have a permanent pool of water in the main basin.	There is no opportunity for settling of contaminants between storm events and dilution of stormwater contaminants during storms. Therefore, they are beneficial for erosion and flood control but are ineffective for water quality control.
Wet Ponds	A detention basin designed to temporarily store collected stromwater runoff and release it at a controlled rate through an outlet. These ponds maintain a permanent pool of water between storm events.	A single pond can provide water quality, erosion, and flooding control. The most common stormwater facility in Ontario.
Constructed Wetlands	Dominated by shallow zones (less than 0.5 m). More vegetation can be incorporated into the wetlands with the associated potential for water quality enhancement.	Not as advantageous as wet ponds because, due to their shallow depth, constructed wetlands are more land intensive and their flood control abilities are limited.
Infiltration Basins	May be needed in some situations to provide adequate groundwater recharge. However, water collected from a large area must infiltrate in a relatively small area. Can only be used where there are soils through which water can rapidly flow.	They are ineffective for flood control and pretreatment of stormwater is required to prevent groundwater contamination and clogging of soils.
Filters	Used for water quality control by filtering runoff through a bed of sand or other media. There are many types of filters. May be at the surface or underground, and the filter media may be sand and/or organic material such as peat.	Filters can be incorporated into most parking lot areas and commercial sites.
Vegetated Filter Strips	Usually consist of a small dam and planted vegetation (grass or trees). The dam is constructed perpendicular to the direction of flow and ensures that the flow is spread evenly over the vegetation which filters out pollutants and promotes stormwater infiltration.	Can be used as infiltration control, or a pretreatment control, and are best used adjacent to a buffer strip, watercourse or drainage swale.

* Source: Ontario Ministry of the Environment, 2004.

ıpendix 6.1: Types of Failure Events Which Could Impact on Source Watersheds

ype of Failure Event	Cause of Failure	Suggested Prevention Techniques
Mechanical Failures	May include incidents such as a pump breakdown or valve malfunction.	Regular maintenance and replacing aging equipment lowers the likelihood of breakdowns. Back-up equipment should be on hand.
Ǝnvironmental Failures	May result from extreme weather events including floods, ice storms, hurricanes and forest fires. These events are normally short in duration an somewhat unpredictable and can affect source water quality, and the infrastructure which treats, stores and distributes the drinking water.	Possible protective measures may include construction of dikes or other barriers around the well and related treatment facilities.
andalism / Civil Disturbance	Sabotage can be subtle and unpredictable.	An assessment should be completed to detect where maximum damage can be may be accomplished with minimum effort, material, and danger for the saboteur. Barriers should be established as a means of prevention.
Disgruntled Employee / ecently Released Employee	A troubled employee creates the possibility of gross-negligence or disruptive action which is problematic for a water owner and / or operator.	Upon release, the employee should be asked to return all keys, turn in any sensitive materials, and return any utility grounds passes. A utility should also consider re-keying locks and changing electronic codes for doors and computer systems.
Contamination	One of the most likely sources of contamination is accidental spills.	Regardless of the contaminant type, effective protective procedures or facilities may include: monitoring, detection and identification; alternative sources of water; alternative intake structures at varying reservoir depths; system (on-line) storage in covered tanks; and water purification facilities.
Power Outages	The on-site generation of electricity requires fuel and the distribution of power requires transmission facilities.	Ensure the availability of standby generators, provide sufficient on-line reservoirs and gravity-flow lines to maintain limited distribution, make available portable generators.
Communication Disruption	Communication failures fall into two basic categories: failure of automatic signal equipment and associated telemetry, and failure of communications that link people.	Telemetry protective measures may include precoded operations at pumping stations, elevated reservoirs, intakes, treatment works, etc, which would put equipment on an automatic operating schedule in the event of signal failure. The use of a radio net and cell phones greatly improves and protects person to person communication.
Transportation Failure	Transportation failure can be expected during adverse weather conditions.	Protective measures include stockpiling basic materials, such as chemicals, chlorine, and critical spare parts.

Source: Canadian Council of Ministers of the Environment, 2004.

Appendix 6.2: Number of Spills Reported According to County

County / District	Population in 2001*	2003	Percentage of Total Spills	2004	Percentage of Total Spills
Carleton County	774,072	7	1.7%	8	2.1%
County of Brant	118,485	3	0.7%	0	0.0%
County of Bruce	63,892	8	1.9%	9	2.4%
County of Dufferin	51,013	0	0.0%	1	0.3%
County of Elgin	81,553	7	1.7%	3	0.8%
County Of Essex	374,975	4	1.0%	9	2.4%
County of Frontenac	138,606	4	1.0%	1	0.3%
County of Grey	89,073	8	1.9%	6	1.6%
County of Haliburton	15,085	5	1.2%	2	0.5%
County of Hastings	125,915	7	1.7%	8	2.1%
County of Huron	59,701	7	1.7%	3	0.8%
County of Lambton	126,971	3	0.7%	3	0.8%
County of Lanark	62,495	6	1.4%	4	1.1%
County of Lennox and Addington	39,461	5	1.2%	2	0.5%
County of Middlesex	403,185	11	2.7%	8	2.1%
County of Northumberland	77,497	4	1.0%	7	1.8%
County of Perth	73,675	3	0.7%	5	1.3%
County of Peterborough	125,856	2	0.5%	1	0.3%
County of Renfrew	95,138	14	3.4%	6	1.6%
County of Simcoe	377,050	29	7.0%	24	6.3%
County of Wellington	187,313	16	3.9%	15	4.0%
District Municipality of Muskoka	53,106	7	1.7%	8	2.1%
District of Algoma	118,567	14	3.4%	12	3.2%
District of Cochrane	85,247	12	2.9%	11	2.9%
District of Kenora	61,802	20	4.8%	9	2.4%
District of Manitoulin	12,679	2	0.5%	1	0.3%
District of Nipissing	82,910	13	3.1%	15	4.0%
District of Parry Sound	39,665	7	1.7%	2	0.5%
District of Rainy River	22,109	1	0.2%	1	0.3%
District of Sudbury	22,894	14	3.4%	16	4.2%
District of Thunder Bay	150,860	14	3.4%	17	4.5%
District of Timiskaming	34,442	3	0.7%	6	1.6%
Haldimand County	43,728	0	0.0%	4	1.1%
Chatham-Kent Division	107,709	1	0.2%	1	0.3%
Municipality Of Metropolitan Toronto	2,481,494	19	4.6%	20	5.3%
Norfolk County	60,847	2	0.5%	11	2.9%
Prince Edward County	24,901	6	1.5%	4	1.1%
Regional Municipality Of Durham	506,901	4	1.0%	9	2.4%
Regional Municipality of Halton	154,033	28	6.8%	14	3.7%
Regional Municipality of Niagara	410,574	20	4.8%	16	4.2%
Regional Municipality of Peel	988,948	9	2.2%	8	2.1%
Regional Municipality Of Sudbury	155,268	1	0.2%	0	0.0%
Regional Municipality of Waterloo	438,515	11	2.7%	14	3.7%
Regional Municipality of York	729,254	16	3.9%	16	4.2%
Restructured County of Oxford	99,270	2	0.5%	5	1.3%
United Counties of Leeds and Grenville	96,606	7	1.7%	11	2.9%
United Counties Of Prescott & Russell	76,446	5	1.2%	4	1.1%
United Counties of Stormont, Dundas and Glengarry	109,522	5	1.2%	5	1.3%
Victoria County	69,179	4	1.0%	3	0.8%
Wentworth County	490,268	14	3.4%	12	3.2%

*Source: Statistics Canada, 2001

Sources of Spills	County									Total	% of Total Spills
	County of Middlesex	Regional Municipality of Niagara	Regional Municipality of Waterloo	Wentworth County	Regional Municipality Of Durham	Regional Municipality of York	Carleton County	Regional Municipality of Peel	Municipality Of Metropolitan Toronto		
	pop 403185	pop. 410574	pop 438515	pop. 490268	pop 506901	pop 729254	pop 774072	pop. 988948	pop. 2481494		
Sewage Treatment Plant Effluent	2	3	4	2	0	3	2	3	8	**27**	**24.32%**
Combined Sewer Overflow	0	0	0	2	0	0	0	0	0	**2**	**1.80%**
Sanitary Sewer Overflow	1	1	2	3	1	3	0	0	4	**15**	**13.51%**
Septic System Failure	0	3	0	2	0	2	1	0	0	**8**	**7.21%**
Sewer System Failure	0	7	2	4	1	6	2	5	5	**32**	**28.82%**
Sewage Treatment Plant Bypass	8	4	3	1	0	2	1	1	2	**22**	**19.82%**
Biosolids Storage	0	1	0	0	1	0	0	0	0	**2**	**1.80%**
Septage Application	0	0	0	0	1	0	0	0	0	**1**	**0.90%**
Drinking Water Treatment Plant Filter Backwash	0	1	0	0	0	0	0	0	0	**1**	**0.90%**
Stormwater pond failure	0	0	0	0	0	0	1	0	0	**1**	**0.90%**
Total	**11**	**20**	**11**	**14**	**4**	**16**	**7**	**9**	**19**	**111**	**100.00%**

Appendix 6.4: Contaminants Released by Spills in Larger Counties for 2003

Contaminant	County									Total	% of Total Spills
	County of Middlesex	Regional Municipality of Niagara	Regional Municipality of Waterloo	Wentworth County	Regional Municipality Of Durham	Regional Municipality of York	Carleton County	Regional Municipality of Peel	Municipality of Metropolitan Toronto		
	pop 403185	pop 410574	pop 438515	pop. 490268	pop 506901	pop 729254	pop. 774072	pop 988948	pop. 2481494		
Raw Sewage	6	13	4	12	2	13	2	5	10	67	60.36%
Primary Unchlorinated Sewage	1	2	1	0	0	0	0	0	1	5	4.50%
Primary Chlorinated Sewage	1	0	2	0	0	2	1	2	0	8	7.21%
Secondary Unchlorinated Sewage	0	0	0	0	0	0	0	0	2	2	1.80%
Sewage Sludge	0	2	3	1	0	0	1	0	4	11	9.91%
Partially Treated Sewage	0	0	1	0	0	0	0	0	0	1	0.91%
Untreated Wastewater Effluent	2	0	0	1	0	1	1	0	0	5	4.50%
Final Chlorinated Sewage Effluent	0	0	0	0	0	0	0	2	1	3	2.70%
Biosolids	0	1	0	0	1	0	0	0	0	2	1.80%
Liquid Septage	0	0	0	0	1	0	0	0	0	1	0.91%
UV'd Sewage	1	0	0	0	0	0	0	0	0	1	0.91%
Filter Backwash	0	1	0	0	0	0	0	0	0	1	0.91%
Activated Sludge	0	1	0	0	0	0	0	0	0	1	0.91%
Stormwater	0	0	0	0	0	0	1	0	0	1	0.91%
Digester Sludge	0	0	0	0	0	0	1	0	1	2	1.80%
Total	**11**	**20**	**11**	**14**	**4**	**16**	**7**	**9**	**19**	**111**	**100.00%**

Appendix 6.5: Sources of Spills in Larger Counties for 2004

Sources of Spills	County									Total	% of Total Spills
	County of Middlesex	Regional Municipality of Niagara	Regional Municipality of Waterloo	Wentworth County	Regional Municipality Of Durham	Regional Municipality of York	Carleton County	Regional Municipality of Peel	Municipality Of Metropolitan Toronto		
	pop. 403185	pop. 410574	pop 438515	pop. 490268	pop. 506901	pop. 729254	pop. 774072	pop 988948	pop. 2481494		
Sewage Treatment Plant Effluent	0	3	7	4	3	2	1	0	7	**27**	**24.32%**
Sanitary Sewer Overflow	0	1	1	0	1	0	1	1	1	**6**	**5.41%**
Combined Sewer Overflow	0	1	0	1	0	0	0	0	2	**4**	**3.60%**
Septic System Failure	0	0	0	3	1	1	0	1	3	**9**	**8.11%**
Sewer System Failure	2	4	2	3	1	12	5	5	2	**36**	**32.43%**
Sewage Treatment Plant Bypass	4	5	3	1	2	1	1	1	4	**22**	**19.82%**
Manure Application	0	1	0	0	0	0	0	0	0	**1**	**0.90%**
Manure Storage	1	0	0	0	0	0	0	0	1	**2**	**1.80%**
Biosolids Storage	1	0	0	0	0	0	0	0	0	**1**	**0.90%**
Biosolids Application	0	1	1	0	1	0	0	8	0	**11**	**9.91%**
Total	**8**	**16**	**14**	**12**	**9**	**16**	**8**	**8**	**20**	**111**	**100.00%**

Appendix 6.6: Contaminants Released by Spills in Larger Counties for 2004

Contaminant	County									Total	% of Total Spills
	County of Middlesex	Regional Municipality of Niagara	Regional Municipality of Waterloo	Wentworth County	Regional Municipality Of Durham	Regional Municipality of York	Carleton County	Regional Municipality of Peel	Municipality Of Metropolitan Toronto		
	pop 403185	pop 410574	pop. 438515	pop. 490268	pop. 506901	pop. 729254	pop. 774072	pop. 988948	pop 2481494		
Raw Sewage	4	11	4	8	5	14	7	7	13	73	65.76%
Primary Unchlorinated Sewage	0	0	1	0	1	0	1	1	0	4	3.60%
Primary Chlorinated Sewage	1	1	3	0	0	0	0	0	0	5	4.50%
Secondary Chlorinated Sewage	1	0	0	0	1	0	0	0	0	2	1.80%
Manure	1	1	0	0	0	0	0	0	1	3	2.70%
Sewage Sludge	0	0	4	2	1	1	0	0	3	11	9.91%
Untreated Wastewater Effluent	0	1	1	1	0	1	0	0	1	5	4.50%
Final Chlorinated Sewage Effluent	0	1	0	1	0	0	0	0	2	4	3.60%
Biosolids	1	1	1	0	1	0	0	0	0	4	3.60%
Total	**8**	**16**	**14**	**12**	**9**	**16**	**8**	**8**	**20**	**111**	**100.00%**

Appendix 6.7: Sources of Spills in Smaller Counties for 2003

Source of Spills	County										Total	% of Total Spills
	District of Manitoulin	County of Haliburton	District of Rainy River	District of Sudbury	Prince Edward County	District of Timiskaming	County of Lennox and Addington	District of Parry Sound	District Municipality of Muskoka	County of Huron		
	pop. 12679	pop. 15085	pop. 22109	pop. 22894	pop 24901	pop. 34442	pop. 39461	pop. 39665	pop. 53106	pop 59701		
Sewage Treatment Plant Effluent	0	1	0	4	5	1	1	0	0	1	13	22.81%
Septic System Failure	0	2	0	1	0	0	0	0	1	1	5	**8.77%**
Sanitary Sewer Overflow	0	1	0	3	0	0	1	4	2	0	11	**19.30%**
Sewer System Failure	0	1	0	2	0	0	1	1	4	0	9	**15.79%**
Sewage Treatment Plant Bypass	2	0	1	4	1	2	2	2	0	4	18	31.58%
Manure Storage	0	0	0	0	0	0	0	0	0	1	1	**1.75%**
Total	**2**	**5**	**1**	**14**	**6**	**3**	**5**	**7**	**7**	**7**	**57**	**100.00%**

Appendix 6.8: Contaminants Released by Spills in Smaller Counties for 2003

Contaminant	County										Total	% of Total Spills
	District of Manitoulin	County of Haliburton	District of Rainy River	District of Sudbury	Prince Edward County	District of Timiskaming	County of Lennox and Addington	District of Parry Sound	District Municipality of Muskoka	County of Huron		
	pop. 12679	pop. 15085	pop. 22109	pop. 22894	pop. 24901	pop. 34442	pop. 39461	pop. 39665	pop 53106	pop. 59701		
Raw Sewage	0	4	0	4	0	0	3	1	7	1	20	35.09%
Primary Unchlorinated Sewage	1	0	0	0	0	0	0	0	0	0	1	1.75%
Primary Chlorinated Sewage	1	0	1	5	1	3	2	5	0	3	21	36.84%
Manure	0	0	0	0	0	0	0	0	0	1	1	1.75%
Sewage Sludge	0	1	0	2	4	0	0	1	0	0	8	14.04%
Untreated Wastewater Effluent	0	0	0	1	0	0	0	0	0	1	2	3.51%
Final Chlorinated Sewage Effluent	0	0	0	1	0	0	0	0	0	1	2	3.51%
Partially Treated Sewage	0	0	0	1	0	0	0	0	0	0	1	1.75%
Secondary Chlorinated Sewage	0	0	0	0	1	0	0	0	0	0	1	1.75%
Total	**2**	**5**	**1**	**14**	**6**	**3**	**5**	**7**	**7**	**7**	**57**	**100.00%**

Appendix 6.9: Sources of Spills in Smaller Counties for 2004

Sources of Spills	County												**Total**	**% of Total Spills**
	District of Manitoulin	County of Haliburton	District of Rainy River	District of Sudbury	Prince Edward County	District of Timiskam ing	County of Lennox and Addington	District of Parry Sound	Haldiman d County	County of Dufferin	District Municipal ity of Muskoka	County of Huron		
	pop 12679	pop 15085	pop. 22109	pop. 22894	pop 24901	pop 34442	pop. 39461	pop 39665	pop 43728	pop. 51013	pop. 53106	pop 59701		
Sewage Treatment Plant Effluent	0	0	0	3	4	1	1	0	2	1	2	1	**15**	30.00%
Sanitary Sewer Overflow	0	0	0	1	0	0	0	0	0	0	0	0	**1**	**2.00%**
Septic System Failure	0	1	0	9	0	0	0	0	0	0	2	0	**12**	24.00%
Sewer System Failure	0	1	0	0	0	2	0	2	1	0	3	1	**10**	**20.00%**
Sewage Treatment Plant Bypass	1	0	1	3	0	3	1	0	0	0	1	0	**10**	**20.00%**
Manure Application	0	0	0	0	0	0	0	0	0	0	0	1	**1**	**2.00%**
Biosolids Storage	0	0	0	0	0	0	0	0	1	0	0	0	**1**	**2.00%**
Total	**1**	**2**	**1**	**16**	**4**	**6**	**2**	**2**	**4**	**1**	**8**	**3**	**50**	**100.00%**

Appendix 6.10: Contaminants Released by Spills in Smaller Counties for 2004

Contaminant	County												Total	% of Total Spills
	District of Manitoulin	County of Haliburton	District of Rainy River	District of Sudbury	Prince Edward County	District of Timiskaming	County of Lennox and Addington	District of Parry Sound	Haldimand County	County of Dufferin	District Municipality of Muskoka	County of Huron		
	pop. 12679	pop. 15085	pop. 22109	pop 22894	pop. 24901	pop 34442	pop. 39461	pop. 39665	pop 43728	pop. 51013	pop. 53106	pop. 59701		
Raw Sewage	1	2	0	8	1	3	2	1	1	0	7	1	**27**	**54.00%**
Primary Unchlorinated Sewage	0	0	0	1	0	0	0	0	0	0	1	0	**2**	**4.00%**
Primary Chlorinated Sewage	0	0	1	5	0	3	0	1	0	0	0	0	**10**	**20.00%**
Manure	0	0	0	0	0	0	0	0	0	0	0	1	**1**	**2.00%**
Sewage Sludge	0	0	0		2	0	0	0	0	0	0	0	**2**	**4.00%**
Untreated Wastewater Effluent	0	0	0	1	0	0	0	0	2	0	0	0	**3**	**6.00%**
Final Chlorinated Sewage Effluent	0	0	0	1	1	0	0	0	0	0	0	1	**3**	**6.00%**
Biosolids	0	0	0	0	0	0	0	0	1	1	0	0	**2**	**4.00%**
Total	**1**	**2**	**1**	**16**	**4**	**6**	**2**	**2**	**4**	**1**	**8**	**3**	**50**	**100.00%**

Appendix 6.11: Summary of the Top Five Counties with the Largest Number of Spills in 2003 and their Associated Contaminant Sources

County	Contaminant Source								Total
	Sewage Treatment Plant Effluent	Septic System Failure	Sewer System Overflow	Biosolids Storage Failure	Septage Appl. Failure	Sewer System Failure	Sewage Treatment Plant Bypass	Drinking Water Treatment Filter Backwash	
Simcoe	6	6	2	0	0	12	3	0	**29**
Toronto	8	0	5	0	0	4	2	0	**19**
Halton	7	2	0	1	1	5	11	1	**28**
Niagara	3	3	1	1	0	7	4	1	**20**
Kenora	2	4	2	0	0	8	4	0	**20**
Total	**26**	**15**	**10**	**2**	**1**	**36**	**24**	**2**	**116**
% of Total Spills	**22.4%**	**12.9%**	**8.6%**	**1.7%**	**0.8%**	**31.0%**	**20.7%**	**1.7%**	**100.0%**

Appendix 6.12: Summary of the Top Five Counties with the Largest Number of Spills in 2003 and their Associated Contaminant Types

Contaminant Type	County					Total	% of Total Spills
	Simcoe	Toronto	Halton	Niagara	Kenora		
Raw Sewage	22	10	17	13	14	**76**	**65.50%**
Primary Unchlorinated Sewage	1	1	1	2	0	**5**	**4.30%**
Primary Chlorinated Sewage	2	0	3	0	4	**9**	**7.80%**
Secondary Unchlorinated Sewage	0	2	0	0	0	**2**	**1.72%**
Secondary Chlorinated Sewage	1	0	0	0	0	**1**	**0.86%**
Digester Sludge	0	1	0	0	0	**1**	**0.86%**
Sewage Sludge	1	4	1	2	0	**8**	**6.90%**
Activated Sludge	0	0	0	1	0	**1**	**0.86%**
Biosolids	0	0	1	1	0	**2**	**1.72%**
Liquid Septage	0	0	1	0	0	**1**	**0.86%**
Untreated Wastewater Effluent	1	0	3	0	2	**6**	**5.17%**
Treated Wastewater Effluent	0	1	0	0	0	**1**	**0.86%**
Final Unchlorinated Sewage Effluent	1	0	1	0	0	**2**	**1.72%**
Wastewater Backwash	0	0	0	1	0	**1**	**0.86%**
Total	**29**	**19**	**28**	**20**	**20**	**116**	**100.00%**

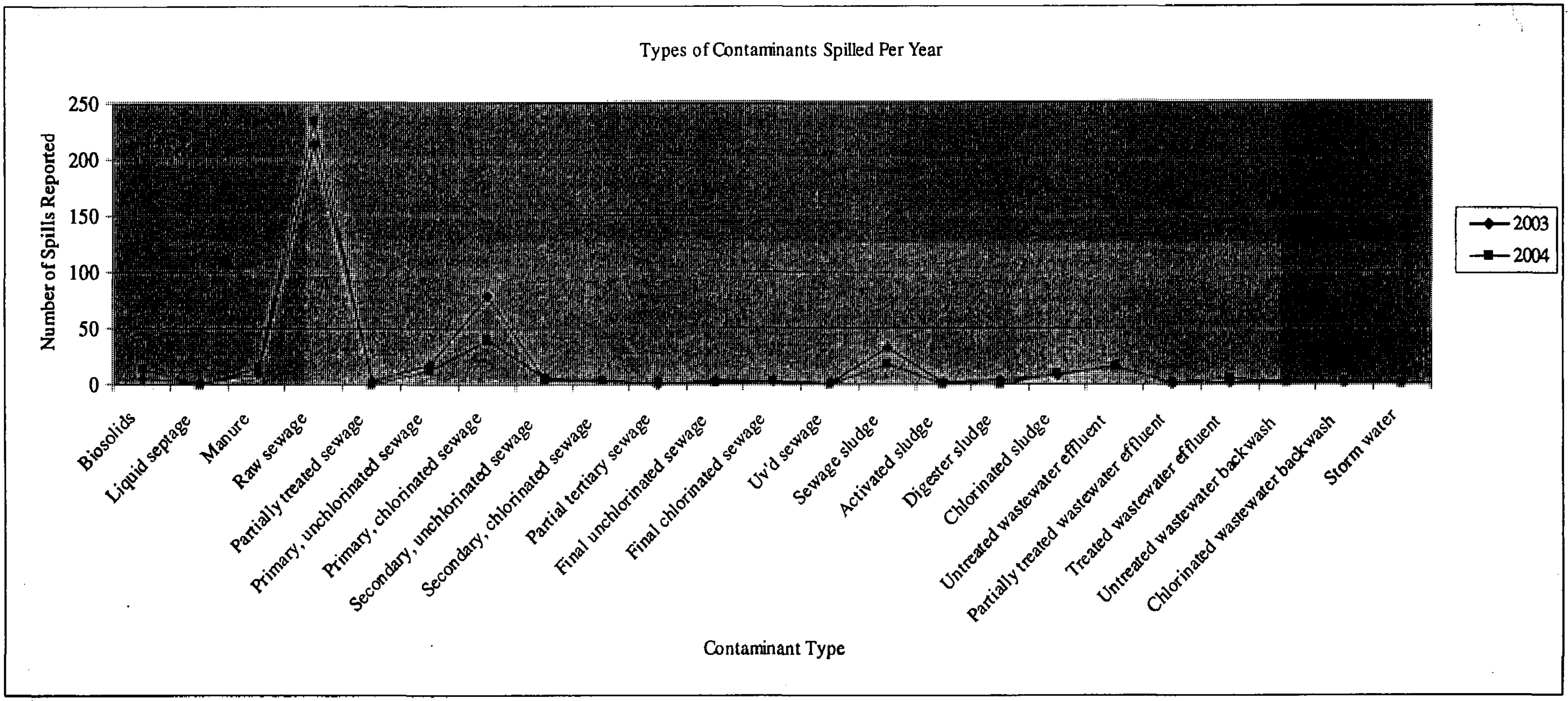
Appendix 6.13: Summary of the Top Five Counties with the Largest Number of Spills in 2004 and their Associated Contaminant Sources

County	Contaminant Source									Total
	Sewage Treatment Plant Effluent	Septic System Failure	Sanitary Sewer Overflow	Biosolids Appl. Failure	Sewer System Failure	Sewage Treatment Plant Bypass	Combined Sewer Overflow	Manure Appl.	Manure Storage	
Simcoe	5	3	4	0	10	2	0	0	0	**24**
Toronto	7	3	1	0	2	4	2	0	1	**20**
Thunder Bay	4	3	0	0	1	8	1	0	0	**17**
Niagara	3	0	1	1	4	5	1	1	0	**16**
Sudbury	3	0	1	0	9	3	0	0	0	**16**
Total	**22**	**9**	**7**	**1**	**26**	**22**	**4**	**1**	**1**	**93**
% of Total Spills	**23.70%**	**9.68%**	**7.52%**	**1.08%**	**27.96%**	**23.66%**	**4.30%**	**1.08%**	**1.08%**	**100.00%**

Appendix 6.14: Summary of the Top Five Counties with the Largest Number of Spills in 2004 and their Associated Contaminant Types

Contaminant Type	County					Total	% of Total Spills
	Simcoe	Toronto	Thunder Bay	Niagara	Sudbury		
Raw Sewage	20	13	8	11	8	**60**	**64.5%**
Primary Unchlorinated Sewage	0	0	0	0	1	**1**	**1.1%**
Primary Chlorinated Sewage	0	0	7	1	5	**13**	**14.0%**
Secondary Unchlorinated Sewage	2	0	0	0	0	**2**	**2.2%**
Manure	0	1	0	1	0	**2**	**2.2%**
Sewage Sludge	1	3	0	0	0	**4**	**4.3%**
Biosolids	1	0	0	1	0	**2**	**2.2%**
Untreated Wastewater Effluent	0	1	2	1	1	**5**	**5.4%**
Treated Wastewater Effluent	0	2	0	1	1	**4**	**4.3%**
Total	**24**	**20**	**17**	**16**	**16**	**93**	**100.0%**

6.15: Graph of Types and Quantity of Contaminant Spills in 2003 and 2004



Appendix 6.16: Summary of the Sources of Spills Reported in 2003 and Their Causes

Source of Spill	Cause of Failure									Total
	Equipment Failure	Operator Error	Power Failure	Weather	Fire	Electrical Failure	Vandalism	Unknown	Other	
Biosolid Appl.	1	1	0	0	0	0	0	1	0	**3**
Biosolid Storage	0	3	0	0	0	0	0	0	0	**3**
Septage Appl.	1	1	0	0	0	0	0	0	0	**2**
Manure Appl.	0	0	0	4	0	0	0	0	0	**4**
Manure Storage	3	2	0	0	0	0	0	1	0	**6**
Combined Sewer Overflow	3	0	1	1	0	0	0	0	0	**5**
Sanitary Sewer Overflow	24	1	0	1	1	0	0	7	0	**34**
Septic System Failure	21	2	2	4	1	0	1	4	1	**36**
Sewage Treatment Plant Bypass	30	5	**73**	8	0	1	0	2	0	**119**
Sewage Treatment Plant Effluent	55	12	20	**12**	0	1	0	5	0	**105**
Sewer System Failure	**63**	**16**	6	4	0	0	1	1	0	**91**
Stormwater Pond Failure	0	0	0	1	0	0	0	0	0	**1**
Drinking Water Treatment Filter Backwash	1	1	1	0	0	0	0	2	0	**5**
Total	**202**	**44**	**103**	**35**	**2**	**2**	**2**	**23**	**1**	**414**

Appendix 6.17: Summary of the Sources of Spills Reported in 2004 and Their Causes

Source of Spill	Cause of Failure									Total
	Equipment Failure	Operator Error	Power Failure	Weather	Fire	Electrical Failure	Vandalism	Unknown	Other	
Biosolid Appl.	4	2	0	0	0	0	0	1	0	**7**
Biosolid Storage	0	4	0	0	0	0	0	0	0	**4**
Septage Appl.	0	0	0	0	0	0	0	0	0	**0**
Manure Appl.	1	5	0	0	0	0	1	1	0	**8**
Manure Storage	2	1	0	2	1	0	0	0	0	**6**
Combined Sewer Overflow	3	0	0	3	0	0	0	0	0	**6**
Sanitary Sewer Overflow	13	0	0	6	0	0	0	2	0	**21**
Septic System Failure	17	6	1	0	0	0	0	5	1	**30**
Sewage Treatment Plant Bypass	52	5	**31**	12	0	1	1	0	0	**102**
Sewage Treatment Plant Effluent	47	17	2	**15**	0	0	1	4	0	**86**
Sewer System Failure	**83**	**19**	0	3	0	0	1	1	0	**107**
Stormwater Pond Failure	0	0	0	0	0	0	0	0	0	**0**
Drinking Water Treatment Filter Backwash	2	0	1	0	0	0	0	0	0	**3**
Total	**224**	**59**	**35**	**41**	**1**	**1**	**4**	**14**	**1**	**380**