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Assessment of the pathogen abatement effects of nutrient management policy : the Ontario Nutrient Management Act, 2002

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Assessment of the Pathogen Abatement Effects of Nutrient Management Policy:
The Ontario Nutrient Management Act, 2002

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ABSTRACT

The Pathogen Abatement Effects of Nutrient Management Policies: The Ontario Nutrient Management Act, 2002

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Master of Applied Science
in the Program of
Environmental Applied Science and Management

Nutrient management strategies and regulations provide for the optimal management of waste materials containing nutrients that may be applied to the land. They are enacted to protect water sources while maximizing the economic and biological value of the nutrients. The province of Ontario has enacted a new Nutrient Management Act (2002), the purpose of which is to enable the province to enact regulations that establish standards for the management of nutrients. Livestock waste not only contains nutrients, but also contains many pathogenic microorganisms such as bacteria, protozoa, and viruses. Although these contaminants are abundant in livestock waste, no legislation has been specifically designed for their control; instead, nutrient management policies are assumed to be proxies for pathogen management. Therefore, the question is, will nutrient management policies that have been designed specifically to control nutrients also ensure a safe drinking water supply through the control of pathogens?

This study focused on four pathogens: *E. coli* O157:H7, *Salmonella, Giardia* and *Cryptosporidium,* and the existing scientific knowledge regarding the fate and transport of these pathogens in agricultural environments. The existing scientific knowledge was then used to analyze the effectiveness of the regulations of the new Nutrient Management Act (2002) at controlling pathogenic microorganisms.

The analysis showed the regulations used to reduce the risk of horizontal and vertical transport of wastes were inadequate at controlling pathogens, although the regulations may have been adequate for the control of nutrients and soil erosion. The scientific literature showed that pathogens have the ability to be transported in many soil types, in tilled soils, and in the absence of rain. The survivability of pathogenic microorganisms further enhances their ability to be transported.

The results of the review of nutrient management policies in Canada, the United States and Europe show that there is a gap when using nutrient management policies to control pathogens. The majority of policies do not address critical pathogen control issues such as herd health, biosecurity practices, and treatments used during storage that could aid in pathogen load reduction. The study concluded that addressing pathogen load is critical because the ability of pathogens to survive and be transported in numerous environments leaves an uncertainty in the effectiveness of the land application regulations at reducing the risk of pathogen contamination.

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Chapter One: Introduction

1.1 Background

Nutrient management strategies and regulations are intended to provide for the optimal management of waste materials containing nutrients that may be applied to land. They are enacted to protect water sources while maximizing the economic and biological value of the nutrients. The Province of Ontario has created a new Nutrient Management Act (Bill 81) which received royal assent on June 27th, 2002. The purpose of the legislation is to enable the province to enact regulations that establish standards for the management of materials containing nutrients[1]. The Act requires farmers and other generators or users of such materials to comply with those standards to ensure that nutrients, such as nitrogen and phosphorous, will be controlled.

Livestock waste not only contains nutrients, but also includes many pathogenic microorganisms such as bacteria, viruses, and protozoa, and it is only recently that concern has been expressed about the possible spread of these pathogens to the human population. The measures laid out in the Nutrient Management Act (2002) aim to control nutrients in manure and municipal biosolids applied to agricultural lands, which also contain pathogens, from reaching ground and surface waters and causing environmental degradation and/or waterborne disease outbreaks, similar to the one that occurred in Walkerton, Ontario, May 2001.

The purpose of the Act is 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). The Nutrient Management Act (2002) does not include drinking water protection as an objective to be achieved by its provisions; nonetheless an end result of the Act will be some protection of human health from pathogen-induced waterborne illness. The Act is based on many current best management practices in nutrient management. The regulations currently being reviewed include specified standards applied to: the size, capacity, and location of

[1] Nutrient control is important when agricultural operations apply nutrients to increase crop productivity and yield because excess concentrations of phosphorous and nitrogen will pollute water sources. Excess phosphorous encourages excessive growth of aquatic plants, depleting the oxygen supply for other plants and wildlife and leading to unsustainable eutrophication. Excess nitrogen in water supplies not only affects environmental health but also human health. Ontario's Drinking Water Objectives require no more than 10ppm of nitrogen in drinking water supplies.

structures that are used to store material containing nutrients; rates of application; the time and manner in which materials containing nutrients may be applied to lands; minimum separation distances between lands to which materials containing nutrients are applied and specified distances to and uses of geographic features, such as open bodies of water, or wells; and vegetated buffer strips.

Historically, it was assumed that pathogenic organisms could not travel great distances through soil due to filtration; however recent studies suggest that bacterial and protozoan transport are significant and lead to the contamination of water sources (Wall, 1998; Brush, 1999). The presence of pathogenic organisms such as *Escherichia coli* O157:H7, *Cryptosporidium parvum* and *Giardia lamblia* in water supplies have been implicated in gastrointestinal illness outbreaks among both immunohealthy and immunocompromised patients (Fleminget al. 1997). Along with extreme viability in the environment, these organisms have minute infectious dose minima. The infectious dose range in humans is very low, ranging from 10-100 organisms (Fleming et al. 1997).

The prevalence of these pathogens is also a cause for concern. Rahn et al. (1997) studied the prevalence of *E. coli* on dairy farms and found that 87.5% of the farms studied were positive for verotoxin-producing *E. coli* (VTEC). As well, Fleming et al. (1997) studied the prevalence of *Cryptosporidium* and determined that 90% of the swine operations examined tested positive, and 65% of the dairy operations with solid manure handling systems. These rates suggest that if manure is improperly managed and is transported through agricultural land to water sources that there is a high risk it will contain a number of microorganisms that are potentially harmful to the public.

Little attention across Canada has been given to developing manure management practices that are specifically designed to deal with pathogens (Goss, 2001) and water pollution (Johns, 2000), although the fact that some humans can become infected only after ingesting 10 oocysts or cysts, and that pathogens are prevalent in multiple hosts, suggest the importance of developing policies to focus on the control of pathogen contamination in drinking water as well as nutrient contamination. These organisms are also of particular concern because *Cryptosporidium* oocysts cannot be controlled by chlorination levels that are safe for use in domestic water supplies (Goss, 2001), and treatment practices require large amounts of water to detect them. The cost to detect and treat these pathogens in drinking water is substantial, therefore treatment measures have been limited and the most effective approach for managing microbiological risks from drinking water is source protection. Due to the common source of nutrients and pathogens in agricultural practices, the Nutrient Management Act (2002) will to some extent act as a pathogen management Act as well, and will help to inhibit pathogen transport and protect water sources. The question is to what extent will it successfully manage pathogens?

It is unclear at this stage whether the Nutrient Management Act (2002) will provide the appropriate mix of regulations that are based on science and those that are socio-economically based. Science-based regulations ensure that the protection of human health from drinking water is guaranteed because of the objective nature and value neutrality of evidence. When facts count, and when human health is at risk, it is wise to require policy to observe the rules of the scientific method (Gori, 1996). In order to ensure that the Nutrient Management Act (2002) will be effective in protecting source water, certain regulations, such as the minimum distance separation requirements, must be determined through scientific analysis and hypothesis testing of pathogen survival and transport to ensure that pathogens cannot survive transportation to water sources. It is the testing of hypotheses that actually establish knowledge firm enough to translate into useful technologies and policies that will guarantee safety (Gori, 1996).

Most jurisdictions throughout Canada and the United States have established recommended agricultural best management practices and guidelines including minimum separation distances (MSDs) for manure application to protect water bodies and drinking water wells from agricultural nutrients, but lack policies specifically created for the control of pathogenic organisms and the risk of waterborne disease outbreaks. It is assumed that the nutrient management policies act as proxies for pathogen management policies; therefore pathogens are essentially non-targeted contaminants controlled under the umbrella of nutrient management. With the control of pathogens being based on nutrient management policies, can the public be certain that human health and water sources are being protected?

1.2 Proposed Hypothesis

Do current policies ensure a safe drinking water supply through the control of pathogens based on objective scientific data?

The new Nutrient Management Act (2002) was to some degree created to protect water bodies from agricultural contaminants and ensure a clean supply of drinking water. Pathogens are one such agricultural contaminant, and are delivered to the environment through manure application. Although the Nutrient Management Act (2002) does not expressly attempt to control the transport of pathogens, it will do so to some degree since both nutrients and pathogens are delivered to the environment through the same agricultural practices. This study determines whether this policy will ensure a safe drinking water supply through the control of pathogens, by determining whether certain regulations within the policy that have been specifically designed to control nutrients and sediments will also control pathogenic organisms. There are significant needs for research in the field of manure management if water resources are to be protected from contaminants originating in manure. One of those needs is to concentrate efforts on determining the fate and transport of pathogens and another is to determine whether policies enacted to protect drinking water sources from nutrients also work to protect water sources from pathogens.

This assessment of pathogen survival and the probability of water contamination, and the regulations imposed to control them, will illustrate to agricultural managers and the public the degree of reliability such regulations achieve in protecting water sources from pathogens and the health of the environment.

1.3 Purpose and Objectives

The purpose of this study is to determine if regulations sufficiently limit pathogen survival and transport to control pathogens in order to protect drinking water supplies. This purpose falls out of the urgent need to both protect Ontario's drinking water supply and assure the public that policy makers are enacting regulations that will maximize the protection of their water and ultimately their health. After the events in Walkerton, the public and the agricultural industry need to be assured that the new policies that will be enacted will make certain that the risk of outbreaks from waterborne pathogens and bacteria will be minimized or eliminated. The events at Walkerton also remind us of the serious effects that waterborne bacteria or pathogens can have on our health if we are not managing them properly. Two ways in which to eliminate this risk are to enact regulations that are based on scientifically proven data and to ensure that all forms of risk, including pathogens and bacteria, will be managed.

There are three major objectives in this study:

1. *To evaluate the fate and transport of pathogens in agricultural soils through research that has already been conducted.*

The purpose of this objective is to determine the lengths that pathogens can be transported, in soils that are similar to Ontario's and other jurisdictions, and compare these lengths to the minimum separation distances that those jurisdictions have developed within their policies.

2. *To evaluate current public policies, and assess whether they have ensured the protection of source water from pathogens.*

The purpose of this objective is to determine how policy makers have developed their manure management or nutrient management guidelines and whether these guidelines include the necessary information to control the transport and survival of pathogens as well.

3. *To evaluate whether nutrient management regulations will ensure protection of source water from pathogens.*

The purpose of this objective is to determine whether the regulations dealing with the transport and survivability of nutrients that are proposed by the Nutrient Management Act (2002) are effective at controlling the transport of pathogens to water bodies, based on my findings from Objective One. This objective also brings together my findings from Objective Two and allows me to identify the strengths and the weaknesses of the Act and its comprehensiveness compared to the others that I have reviewed.

1.4 Outline

The thesis document has been laid out as follows. Chapter Two: Literature Review, discusses five relevant issues to the thesis work including: manure-borne pathogens *E. coli, Cryptosporidium, Giardia,* and *Salmonella*, the treatment and management of agricultural waste, water quality, the risk to human health from manure-borne pathogens, and source protection. Chapter Three: Nutrient Management Policies; examines nutrient management policies and guidelines that have been created and/or enacted in Canada, the United States, and other countries. The examination involves storage guidelines, land application guidelines, and treatment guidelines. Discussion of innovative strategies and the comprehensiveness of the strategies are included. Chapter Four: Transport and Survival of Pathogens, examines existing scientific knowledge regarding viability and transport of pathogenic microorganisms in various agricultural environments including manure and slurry, soil, and water sources. Discussion includes knowledge gaps in the issue. Chapter Five: Pathogen Control using Nutrient Management Policy focuses on whether the regulations in the Nutrient Management Act

(2002) are in convergence with existing scientific knowledge on the subject since most nutrient management regulations are assumed to be proxies for pathogen management[2]. This chapter determines whether the nutrient management strategies ensure the control of pathogens as well and includes a discussion on the variables in pathogen management that have been neglected in the nutrient management strategies. Lastly, Chapter Six discusses the findings and suggests future research efforts in order that this problem can be better examined.

[2] The analysis of these regulations began in May 2002; therefore the regulations analyzed were the draft regulations. In June 2003, the final regulations of the Nutrient Management Act, 2002 were published. With respect to this analysis no major changes resulted by reviewing the most recent set of regulations.

Chapter Two: Literature Review

This literature review is intended to investigate the survival and transportation characteristics of the principle pathogenic microorganisms found in manure. It discusses their importance in agricultural environments and their importance to public health.

The application of livestock manure onto agricultural land is a common practice in most agricultural operations. Instead of being treated as a waste and a nuisance, livestock manure is regarded as a valuable fertilizer resource. Due to its high levels of nitrogen and phosphorous, manure can replace many commercial fertilizers and decrease those costs for agricultural operators. However, spreading manure on agricultural land is not without environmental risk. There is the potential to contaminate water sources through runoff or subsurface transport of contaminants into the groundwater supply. In the past, environmental concerns have focused on nutrient impacts, particularly when farm and non-farm land uses, such as subdivisions, were generally segregated. An additional risk that has not received much attention in the past is the large number of microorganisms that are shed in these wastes and their potential to cause waterborne disease. Historically, the policies and regulations that jurisdictions have enacted, including best management practices to minimize the environmental impact of land application on soil and water resources, have focused on controlling nutrients such as nitrogen and phosphorous. It is also important to note that in Ontario policies were primarily voluntary and not adequately enforced pre-Walkerton (Johns, 2000). Most nutrient management policies and guidelines are assumed to be proxies for microorganism control; therefore there are very few regulations that are specifically intended to control pathogen transport and survival.

2.1 Manure-borne Pathogens

The principle microorganisms of concern are those that are pathogenic, specifically parasitic protozoa and bacteria, because they are capable of causing disease in a host. Pathogenic microorganisms present in livestock waste include but are not limited to *Escherichia coli, Giardia, Cryptosporidium,* and *Salmonella.* Pathogens are of concern not only because they cause disease but because they are extremely abundant in infected livestock manure; cow manure usually contains more than 10^9 colony forming units (CFU) of indigenous bacteria per gram (Jiang et al. 2002). In addition, pathogens in manure raise concerns because they are resistant to a number of environmental factors and can survive for long periods in manure, soil and water environments.

2.1.1 *Escherichia coli* and *E. coli* O157:H7

E. coli are a bacterial species that live in the intestinal tracts of multiple hosts and are shed in feces. *E. coli* O157:H7 differs from other normal intestinal *E. coli* strains because it carries several toxin-producing genes capable of affecting humans. This strain is a fairly new pathogen that was first implicated in disease outbreaks in 1982 and accounts for approximately 1% of all known strains (Kaper and O'Brien, 1998). Cattle are the primary hosts of this pathogen (Jones, 1999), and were first identified as carriers in both Canada and the United States in 1986 (Scottish Executive and Food Standards Agency, 2001). Other animals have also been shown to be carriers, including sheep. In cattle, *E. coli* O157:H7 can reside in the gut with no observable effects on the host. On the other hand, this strain of bacteria is highly infectious to humans and has the capacity to produce lethal toxins in the intestine once it has colonized there (Jones, 1999).

Human infection by *E. coli* can cause a range of symptoms from haemorrhagic colitis (severe bloody diarrhea), haemolytic-uraemic syndrome (HUS) which can lead to kidney damage or the need for blood transfusions, or non-bloody diarrhea. Most patients infected with *E. coli* O157 will experience a bout of bloody diarrhea a few days after oral ingestion and most recover within 2 weeks. Although, when kidney damage does occur, about 50% of those patients will require dialysis (Jones, 1999). Immunocompromised patients, including the elderly, the very young, AIDS patients, or chemotherapy patients, often experience more severe symptoms which have led to fatalities. Although this illness is not common, it is serious since more than half of the patients infected with *E. coli* are hospitalized. *E. coli* O157:H7 causes approximately 40,000 infections and 250 deaths each year in the United States (Russell et al. 2000). Symptoms from infection disappear within a few days and most patients feel healthier in 2 weeks, but patients continue to excrete *E. coli* in their feces for between two to four months (Jones, 1999).

When infected with *E. coli*, hosts, both livestock and humans, can excrete up to 10^9 CFU/g of feces (Jones, 1999; Edberg et al. 2000). This excretion rate compounded with a low infectious dose[3] of *E. coli* in humans makes the control of exposure to this pathogenic bacterium important. The infectious dose at which full symptoms can develop can be as low as 10 cells (Jones, 1999; Russell et al. 2000).

Many studies have been conducted to determine this bacterium's prevalence in agricultural operations and natural environments. Varying degrees of prevalence have been identified which may be due to a number of factors including livestock type or age studied, management factors, sample collection and detection methods or experimental design. In the 1980s when *E. coli* infection was most associated with the consumption of undercooked beef, Mafu et al. (1989) studied the feces of slaughtered cattle and concluded a prevalence of *E. coli* in 99% of the animals studied. This prevalence rate is extremely high and may be so because those cattle had been recently transported. A feedlot study found an approximately 3-fold higher prevalence in cattle recently shipped to feedlots than in randomly selected cattle that had not been recently shipped and had been on feed for several months (Kaper and O'Brien, 1998). In 1997, Hancock et al. studied the prevalence of *E. coli* O157:H7 in dairy herds in the Pacific Northwest and determined that 75% of the herds studied tested positive for *E. coli* O157:H7. Rahn et al. (1997) also studied the prevalence of *E. coli* in dairy farm cattle in Ontario, and concluded that on 87.5% of the farms studied, cattle tested positive for verotoxin-producing *E. coli* (VTEC). The study also concluded that VTEC infection among livestock seems to be both transient, as the infection disappears within a herd in a few months and returns later, as well as seasonal since the greatest numbers of positively-tested livestock were found in the summer months. This finding reiterates Jones (1999) and Chapman et al. (1997) whose work also stated that *E. coli* infection is seasonal with excretion rates being highest in the spring and summer. Chapman concluded that the prevalence of *E. coli* in livestock ranged from 4.8-36.8% throughout the year depending on the season.

There are many studies that prove that this pathogen has the ability to adapt to various environmental pressures. Robertson and Edberg (1997) state that bacteria such as *E. coli* can mutate to a form a new cell with selected traits that enable it to adapt to the environment it is in. Adaptation takes time, therefore if the stresses of the environment are severe and changes are quick, the bacteria are less likely to survive, for example when *E. coli* are heated and/or desiccated. Various environments within an agricultural operation are optimal for *E. coli*

[3] The minimum number of ingested organisms it takes to develop full symptoms.

survival including manure storage tanks, stock piles, water troughs, and agricultural fields. For example, Kudva et al. (1998) showed that *E. coli* can remain viable in non-aerated cattle manure for greater than 21 months, but if the manure piles are aerated, *E. coli* survival is reduced to 4 months. Munch et al. (1987) also showed that the T_{90} [4] of *E. coli* was greater in cattle slurry that had not been aerated compared to manure that had been. Himanthongkham et al. (1999 and 2000) studied the survival of *E. coli* in incubated cow manure and slurry and poultry manure and slurry at various temperatures and showed that persistence is greater under lower temperatures (4°C) than at higher temperatures (20 and 37°C). Given that water troughs in grazing areas have been found to contain *E. coli* O157:H7, Kaper and O'Brien (1998) suggest that water troughs play an important role in the transmission of *E. coli* throughout a herd.

Land application of manure distributes *E. coli* onto soil surfaces and *E. coli* have been found to survive within the soil matrix. Fenlon et al. (2000) showed that *E. coli* can persist in various types of soil, but in loam or clay loam soils it can survive for greater than 175 days. Sjogren (1994) investigated the effects of moisture content on the survival of *E. coli* and determined that in sandy loam soils, *E. coli* could remain viable for 408 days in saturated conditions and 285 days at 15% moisture content. Following an outbreak of gastrointestinal illness associated with *E. coli* found in sheep feces at a Scout Camp in Scotland, Ogden et al. (2002) investigated and determined that *E. coli* persisted for 105 days on the surface of the grassland area.

Because of its persistence in soil environments, it is common for this bacterium to reach water supplies either through adsorption onto soil particles and which are being carried with runoff or leaching through the soil matrix to reach groundwater. Wang and Doyle (1998) studied the survival of *E. coli* in various types of water including lake, municipal and reservoir sources. They concluded that *E. coli* could survive in a viable but non-culturable state in municipal water, reservoir water and lake water for greater than 91 days, 81 days, and 67 days respectively, all at 25°C. McGee et al. (2002) investigated the survival of *E. coli* in farm water in various places within a livestock operation and found that the *E. coli* survived for 14, 24 and 31 days; outdoors in a field, in a farmyard shed, and in a lab at 15°C respectively. Lastly, Warburton et al. (1998) investigated the survival of *E. coli* in bottled spring water and

[4] The time it takes to reduce the number of organisms to below 90% of the initial amount.

discovered that because of the absence of competition from indigenous bacteria, *E. coli* were still detectable after 247 days.

Since a number of recent waterborne disease outbreaks have taken place *E. coli* is becoming much more recognizable to the public, agricultural operators and policy makers. There has also been an increasing amount of research in the last ten years on its survival and transport and how to control it from reaching drinking water supplies. In July 2001 a report was released from the Scottish Task Force on *E. coli*, comprised of experts in a number of areas including public health, agriculture, water quality, and policy. The report discussed the incidence of *E. coli* in the environment, its risk to human health, the effectiveness of existing programs to prevent its infection and future management techniques that may be needed to protect the population from waterborne illness. Currently a number of the Task Force's recommendations are being accepted and implemented into Scotland's Prevention of Pollution from Agricultural Activity code to include more specific recommendations regarding the management of *E. coli.*

2.1.2 *Cryptosporidium*

There are six known species of *Cryptosporidium*, but the only species that is known to cause infection in animals and humans is *C. parvum* (Fleming et al. 1999). *C. parvum* is a microscopic waterborne protozoan parasite that can cause gastrointestinal illness in a wide variety of mammals including humans, cattle, sheep, goats, pigs, and horses (Atwill, 1995; Wall et al., 1998; Tate et al., 2000; Harter et al., 2000). Intestinal illness brought on by *C. parvum* is known as Cryptosporidiosis, an untreatable case of severe watery diarrhea that can last up to several weeks, which is usually accompanied by nausea, vomiting and fevers. In patients with compromised immune systems including the young and elderly, this disease can be fatal (Grazyk et al., 2000; Harter et al., 2000; Tate et al., 2000). Cryptosporidiosis was first identified in cattle in 1971 and by 1972 it was isolated in humans with severe diarrhea (Rose, 1997). *Cryptosporidium* and *Giardia* (see 2.1.3) are both protozoan parasites; infected hosts shed cysts or oocysts, in the case of *C. parvum*, into feces. These oocysts are tiny oval eggs, 4-6 μm in diameter, that are capable of surviving in the environment and can establish infection in another host through oral ingestion (Fleming et al. 1999; Harter et al. 2000) Zoonotic[5] transmission is very common as a means of spreading the disease. Many animals have been

[5] Animal to human.

implicated in the transmission of the infection to humans (Rose 1997); see Appendix 2.1 for a list of the animals and the studies that are cited. In cattle, infection and shedding of the oocysts is concentrated in calves under a month of age (Olson et al. 1999), although there have been reports that older cattle have shed the oocysts as well (Atwill, 1995). Grazyk et al. (2000) studied the correlation between *Cryptosporidium* infection and age of cattle; they found that the prevalence of oocyst-positive calf manure samples (68%) was statistically higher than the prevalence (26%) observed for the samples originating from heifers and cows.

Once ingested, excystation of the oocyst occurs within the small intestine of the host. Toxic sporosites are released and attack the epithelium. Reproduction cycles take place and oocysts are shed in vast numbers. Infected humans and animals can pass up to 10 billion *Cryptosporidium* oocysts per day (Marshal et al., 1997; Atwill, 1995; Harter et al., 2000; Pell, 1997). Symptoms of infection can last up to 18 days in humans but even after infected patients have recovered, they may continue to excrete large numbers of the protozoan for up to a few months. Like *E. coli*, the infectious dose of this pathogen is very low, therefore only a few infected people or animals are capable of contaminating large amounts of water (Olson et al. 1999). Due to the pathogen's low infectious dose and hardy oocyst, it is able to survive and persist in the agricultural environment.

Fleming et al. (1997) studied the prevalence of *Cryptosporidium* in agricultural operations in Ontario and found that *Cryptosporidium* was more prevalent in swine operations than in dairy operations with either liquid or solid manure handling systems. 90% of swine operations tested positive for *Cryptosporidium* at least once throughout the study, whereas 65 and 50% of dairy farms with solid and liquid manure handling systems tested positive, respectively. Another study conducted in Quebec by Ruest et al. (1998) found that 88% of 505 dairy farms tested in the province were positive for *Cryptosporidium.* In 1991, LeChevalier et al. (1991a, 1991b) found that 88% of raw water and 27% of filtered water samples tested were infected with *Cryptosporidium.*

Cryptosporidium has been shown to retain its infectivity in the environment for long periods of time, particularly when associated with fecal material (Grazyk et al. 2000). Robertson et al. (1992) studied cattle manure inoculated with 2.8×10^7 CFU/25L of *C. parvum* and found that after 176 days, 36.9% of the oocysts were still viable. Olson et al. (1999) studied the survival of *Cryptosporidium* in calf feces at varying temperatures and concluded that at -4, 4, and 25°C, oocysts remained viable for greater than 84, 56, and 28 days respectively. Olson also studied the survival of *Cryptosporidium* in soil in a laboratory environment and found that at temperatures of -4 to 4°C the pathogen survived for greater than 84 days. This ability to survive in soil and manure allows oocysts the chance to be transported in runoff from fields or drainage from manure storage areas into water sources where it has also been shown that they can persist. For example, Robertson et al. (1992) studied the viability of *C. parvum* in river water and tap water. There was no significant difference in the results of the two experiments and the research team concluded that after 176 days approximately 1% of the oocysts remained viable. Although 1% does not seem great, Robertson et al. used an inoculation containing 2.8×10^7 oocysts, therefore 2,800,000 oocysts remained viable after 176 days. Olson et al. (1999) also studied the survival rate of *Cryptosporidium* in sterile distilled water at various temperatures. They found that *Cryptosporidium* survived better at lower temperatures (-4°C and 4°C) than at higher temperatures (25°C) but remained viable in all situations tested for greater than 70 days. Other significant factors affecting the survival of *Cryptosporidium* in surface waters include the presence of predators, and exoenzymes produced by autochthonous microorganisms. The ability of *Cryptosporidium* to survive in drinking water is a concern to public health officials and water treatment plant (WTP) operators. *C. parvum* is one of the most difficult microorganisms to control because it is resistant to chlorination at levels that are safe for treatment and human consumption (Atwill, 1995; Pell, 1997; Gostin et al. 2000), therefore WTPs that use chlorination as a means of protection are essentially overlooking *C. parvum*. There are many water treatment facilities that did not give appropriate attention to *Cryptosporidium* in their treatment processes until it was too late. In 1993 and 1994, one-third of all waterborne disease outbreaks in the United States were attributed to either *Cryptosporidium* or *Giardia* (Pell, 1997).

2.1.3 *Giardia*

Giardia is similar to *Cryptosporidium* in that it is a common microscopic protozoan parasite that infects the intestinal tract of its host and has been responsible for waterborne disease outbreaks worldwide (Fleming et al., 1999; Olson et al., 1999). The species of most concern is *G. lamblia* because it is the strain that is infectious to mammals and birds (Fleming et al., 1999; Olson et al., 1999). The environmentally hardy state of *Giardia* is a cyst. These cysts are football shaped eggs 8-10μm in diameter, slightly larger than *Cryptosporidium,* and are excreted in the feces of infected hosts. When ingested, the cyst passes through the stomach and excystation takes place due to the amount of acid in the stomach environment (Marshall et al. 1997). Infection occurs via the fecal-oral route and is zoonotic, therefore agricultural operators must take precautions. *Giardia* infection results in a disease called Giardiasis, otherwise known as beaver fever[6]. Giardiasis results in severe diarrhea and weight loss in cattle and humans (Olson et al. 1999; Mapfumo et al. 2002). The main reservoirs for *Giardia* cysts on farms are animals younger than six months. Infected animals and humans can pass up to 10 million cysts per gram of feces (Olson et al, 1999), therefore it takes only a small number of infected patients to contaminate water sources. Like *C. parvum* oocysts, *Giardia* cysts are hardy and resistant to many environmental stressors including water treatment processes (Olson et al. 1999; Hooda et al. 2000), therefore due to the large numbers of cysts that can be passed per day, prevention of the disease is important. It is also important to control the spread of the disease because the infectious dose for humans can be as low as 10 cysts (Olson et al. 1999; Pell, 1997; Mapfumo et al. 2002).

Prevalence of *Giardia* in agricultural operations has been reported to be as high as 67% in swine operations, Xiao et al. (1994) reported the prevalence in swine operations to range between 7 and 67%. Olson et al. (1999) studied prevalence rates in various ages of swine and found that prevalence was greater in adult swine (19%) than in younger animals (3%). In a British Columbia province-wide survey, 68% of raw water samples and 59% of chlorinated samples were cyst-positive (Isaac-Renton et al. 1996). None of the tested sites were defined as pristine, and many had agricultural operations nearby; none had restricted access and none were downstream from large urban sewage discharges. LeChavalier et al. (1991a and 1991b) also studied the presence of *Giardia* cysts in raw and filtered water in the United States and detected cysts in 81% of the raw water samples and 17% of the filtered samples. These studies have shown that *Giardia* is resistant to treatment processes and therefore it is not surprising that in 1993 and 1994, it was implicated along with *Cryptosporidium,* in one-third of all waterborne disease outbreaks. These statistics show why the control of this pathogen's spread is essential in protecting public health.

[6] It is known as 'beaver fever' because beaver are common carriers of the organism and shed it into natural waterways. Many campers who drink river water have been infected with Giardia and experience severe bouts of diarrhea.

2.1.4 *Salmonella*

Salmonella are gram-negative bacteria. There are more than 1200 types of *Salmonella*, but only a selected few cause illness in animals and humans (Nova Scotia Agricultural College, 2002). *Salmonella typhimurium* and *Salmonella enteriditis* are the most common strains of *Salmonella* that have caused human illness in North America (Centre for Disease Control, 2003). Illnesses include typhoid fever and food poisoning. *Salmonella* live in the intestinal tract of their host and are transmitted via the fecal-oral route, usually through contaminated food or water. Once *Salmonella* are ingested, they make their way to the intestine. Once in the intestine, they attach to the wall and penetrate the wall to make their way into the liver or spleen. In these organs, *Salmonella* can reproduce and make its way back to the intestine (Jones and Matthews, 1975). The most common disease called Salmonellosis, causes patients to develop diarrhea, fever, and severe cramps that can last anywhere from 4-7 days. Most patients recover without treatment but there are severe cases in which dehydration can take place and patients may need to be hospitalized. If the infection enters the bloodstream, proper treatment with antibiotics is necessary and some cases have been fatal (Centre for Disease Control, 2003). Patients with impaired immune systems, the elderly and infants, also may suffer more severe symptoms. Cattle are the primary carriers of the bacteria and can survive without showing symptoms or shedding the bacteria in their feces (Clinton et al., 1979; Kearney et al., 1993). When hosts undergo various stresses, they can become active carriers of the disease and shed the organisms (Clinton et al., 1979). Cattle normally excrete less than 1000 organisms per gram of manure when infected (Clinton et al., 1979). The infective dose for humans can be low as 15-20 cells, and depends on the age and health of the host as well as strain differences in the bacteria. The danger in controlling *Salmonella* infection is that it does have such a low infection dose and healthy carriers can spread the disease unknowingly into pastures and water supplies.

In agricultural operations, *Salmonella* are most often found in swine and poultry manure (Goss et al. 2001), although their prevalence in cattle manure can at times be significant. Jones and Matthews (1975) examined cattle slurry for pathogenic bacteria and found a *Salmonella* incidence rate of 11%. The authors note that this conclusion was based on one examination and the actual contamination rate may be even higher. However, this rate seems consistent with Clinton et al. (1979) who also studied the incidence of *Salmonella* in feedlot manure and found that of the 505 pens sampled, 49 were positive (9%) for the bacteria. The authors also noted those operations, where *Salmonella* were present, had a higher incidence rate within the herd. When *Salmonella* are excreted into the environment they can persist for some time. Tamasi (1981) studied the survival of *Salmonella* in liquid manure when it was applied to garden soil and sand. On garden soil, the bacteria survived for 96 days at 8°C and in the sand for 131 days. Tamasi also examined the transport of the bacteria under the same conditions and found that they could travel in excess of 160cm in the soil matrix. These transport and survival rates allow for the potential of *Salmonella* to reach distant water supplies. Bitton et al. (1983) have shown that if *Salmonella* could make its way into groundwater sources they can survive for longer than 15 days. Any microorganisms capable of being suspended in water can be carried great distances through a watershed. Therefore, the bacteria and protozoa discussed have this ability and their control may require management at the source in agricultural livestock operations.

2.2 The Treatment and Management of Agricultural Wastes

Land application of agricultural waste is an opportunity to turn a waste source into a valuable resource. Considering that in Ontario alone, 30.9 billion litres of manure were produced in 1996, this is an important use (Goss et al. 2001). Miller et al. (1989) computed that the manure produced in Ontario in 1989 had a fertilizer replacement value of $158 million. Unfortunately, this method of reuse and disposal is not without risk due to the large amounts of nutrients and microorganisms that are contained in this waste. Firstly, these natural fertilizers are much more difficult to handle because without testing for every nutrient and microorganism there is no way of knowing exactly how much is contained in the waste. Whereas in store-bought fertilizer the exact amounts of nutrients are known and no microorganisms will be added. Secondly, it has been shown that the microorganisms contained in the waste can survive in various environments under varying temperatures and saturations. It was assumed that bacteria had a very short life once outside the host, but Conboy and Goss (2001) state that because most of the microorganisms in a farm environment have been excreted with feces, their survival is enhanced due to the presence of organic matter and a carbon source. This allows the microorganisms to persist in an isolated and protected environment. This fact, as well as the fact that many pathogenic organisms such as *Cryptosporidium* are resistant to chlorination and the normal treatment processes at water utilities, strengthens the argument for the careful treatment and management of agricultural wastes at the farm level.

Most provinces and states in North America have enacted policies or have best management guidelines in place regarding the handling, and utilization of agricultural waste. The objective of these best management practices[7] (BMPs) is to reduce the pollution potential of agricultural waste. Although most of these policies and guidelines focus on the nutrient content of manure and its effects on the environment and human health, these management practices have been used as proxies for microorganism control as well. BMPs ensure that care is taken during the handling, transport, and application of waste so that human exposure to fecal contamination is minimized. Ginnivan et al. (1980) suggested that the bacteriological hazards associated with handling of manure occur at the animal housing facility, the land spreading stage, and the grazing areas of a farm operation. These stages are important because waste is being handled, spread and deposited in the environment where it has the ability to contaminate the soil, nearby water sources including wellheads, farm workers, and other animals. Municipal sewage treatment plants treat human wastes to decrease the number of contaminants before application onto land. But these treatment methods, with the exception of a few larger intensive livestock operations, are generally considered too expensive and unsuitable for typical farm operations, therefore policymakers and regulators have searched for simple methods of controlling contamination that can result from the use of manure (Strauch and Ballarini, 1994).

There are three primary categories of manure management that affect its contamination potential: storage of wastes, land application of wastes, and cattle grazing, and all three have been well studied. Slurry and manure are normally spread on land after spending some time in a storage facility. Land application of manure must be timed appropriately to avoid rain, snow, and frozen soils, therefore manure must be stored until application is optimal. Manure or slurry can reside in a tank, lagoon, or field pile, and the method of storage and various treatments that may be implemented can alter the composition and microbial flora in the waste. Treatment of manure is not required in most jurisdictions and most agricultural operators do not treat manure prior to application, although studies do indicate that treatment can reduce the risk of pathogen

[7] Best management practices (BMPs) are methods, measures, or practices designed to prevent or reduce pollution. They include structural and nonstructural controls as well as operation and maintenance procedures. The practices can be in varying combinations to prevent or control pollution from a particular non-point source.

exposure through application. There are various types of treatment and management methods including aerating slurry or manure, composting or anaerobic digestion of waste. There are also a number of management techniques which can reduce pathogen survival in manure including batch storage or continuous storage of waste.

Composting of manure involves aerobic decomposition of manure at thermophilic temperatures (40-65°C) so that anaerobic, thermophilic bacteria can begin to produce and decompose the manure (Eghball, 1997; NRAES, 1992). Most commonly, composting is conducted in formed windrows of manure stacked outside. An initial mixing of the waste introduces air into the process and it is consumed by the microorganisms. The air supply must be replenished regularly to allow decomposition to continue. Air is supplied by turning the windrows and aerating pore spaces within the pile. When oxygen is supplied and decomposition is taking place, temperatures can reach 65°C (Eghball, 1997; NRAES, 1992). Because of the high temperatures, composting kills pathogenic microorganisms. The USEPA states that in order to successfully kill pathogens, temperatures must be maintained at 55°C or greater for 3 consecutive days. Jones (1980) stated that bacteria such as *Salmonella* could be killed in 5-37 days if temperatures were as high as 70°C. The end product of composted manure is a much easier material to handle than fresh manure because it has decreased in volume and weight and is drier. The compost is also odourless and contains very few if any pathogenic microorganisms, which is optimal for spreading onto cropland. Other advantages include a more stable form of organic nitrogen that is produced which is less susceptible to ammonia loss (NRAES, 1992).

Disadvantages of the process include the time and money it requires. The process is time consuming and heavy equipment is needed to turn the windrows, cement pads are also needed to avoid leaching and runoff at the beginning of the process while the manure is wet. Composted manure also contains less than ½ the amount of nitrogen in fresh manure, sometimes not enough nitrogen to satisfy plant requirements. It not only has fewer nutrients but nutrients are also released at a slower rate and may not become available to the crops until the second growing season after application (Eghball, 1997; NRAES, 1992). Another major disadvantage to composting is that operations that manage slurry, especially swine operations, must take extra steps in the composting process. A necessary porosity is required in the material to allow enough oxygen to penetrate and decomposition to occur, therefore slurry or any other wet materials are inadequate. In order to compost slurry, other material must be added such as leaves, or bedding to add bulk and create pore spaces for oxygen entry. This increases the time and labour of the process as well as the amount of material to handle. There are many advantages and disadvantages to this process and agricultural operators must determine if it is an optimal process to conduct based on their own operations.

Similarly, aeration of animal waste involves storage in which the manure is exposed to a continuous supply of oxygen to promote the growth of aerobic bacteria. Oxygen can be supplied mechanically if the storage site is small or enclosed, such as a tank, or it can be supplied naturally in a lagoon with a large exposed surface area (Fleming, 1986). There are advantages and disadvantages to each method. Mechanically aerated manure can be expensive; there are initial costs of the pump and then the on-going costs of keeping a steady air supply (Fleming, 1986). Lagoons on the other hand are less expensive but can become ineffective in the fall and winter seasons when the weather gets cold because cold temperatures slow down the process. Using lagoons to aerate manure in countries that have cold climates such as Canada can be ineffective, although they are still suitable for storage. Storage tanks obviously also cool in the winter months and the rate of bacterial growth decreases but not as much as would occur in a lagoon.

Aeration also controls odour and this is usually one of the primary reasons that agricultural operators utilize the process, as well as the reduction in nitrogen; generally aeration is not used for its microbial destruction capabilities but this is a secondary advantage. For example, Kudva et al. (1998) examined the effectiveness of aeration on the reduction of survival of *E. coli* in sheep and cattle manure. They found that in sheep manure, aeration decreased the survival of *E. coli* O157:H7 from 21 months to 4 months. *E. coli* survival in cattle manure was also reduced to 47 days when aerated. In 1987, Munch et al. examined aeration's effects on a number of conditions including varying manure type and bacteria. *E. coli* survival was studied in cattle and pig slurry; 6-fold reductions were produced. Munch et al (1987) also examined the effects of aeration on *S. typhimurium* and similar results were found.

Thirdly, anaerobic digestion involves the breakdown of organic waste by bacteria in the absence of oxygen in a completely enclosed system. Microbial growth and biogas production occur naturally at high temperatures without dissolved oxygen (Lusk, 1997; AURI, 2001). The digestion rate can be altered in a treatment facility by increasing temperatures into the mesophilic range (35-40°C) or the thermophilic range (40-60°C). The process is quicker at higher temperatures. The biogas, which is mostly methane, can be used to produce electricity or heat. Odours are controlled because of the microbial decomposition and, at such high temperatures, pathogens are greatly reduced. Kearney et al. (1993) studied the survival of pathogens in anaerobically digested beef cattle slurry and found that *E. coli* reach T_{90} levels in 1.5 days compared to greater than 29 days in normal storage. They also concluded that *S. typhimurium* reached T_{90} levels in 1 day compared to 20 days in normal storage. Unlike composting, digestion can take place with slurry or manure. The end product of anaerobically digested manure is a solid material that can be aged a bit longer into compost (Lusk, 1997). Digestate from slurry digestion is similar to what digested concentrated sewage sludge would be and can be directly spread on agricultural land (Lusk, 1997). This treatment process is more common in Europe than in North America because the process became popular after WWII when energy supplies were cut (Lusk, 1997), although interest in the technology is increasing in North America. Anaerobic lagoons may provide a similar end-product but digesters are smaller, more aesthetically pleasing and allow treatment year-round because they are not weather dependent. Other advantages include the decrease in odours, and pathogenic organisms, as well as the source of energy that is produced. Unlike composting, nutrients are conserved, about 90% of nutrients that enter the system are saved in the process (Lusk, 1997; AURI, 2001), and it is also easier to predict the nutrient content in this treated manure than fresh manure and therefore to apply it more appropriately onto land (ManureNet, 2003). These systems are efficient but they have a very high capital cost, up to $500,000 depending on the amount of manure that will be digested each year (Lusk, 1997). There is also an ongoing operating cost for the digester engine. These costs may be the reason that this treatment process is not utilized as readily in Canada.

2.3 Water Quality

It is the non-point source pollution due to runoff or subsurface transport of contaminants associated with agricultural production that is the major threat to water quality. Other water quality concerns include seepage from field piles of manure, inadequately structured manure storage and livestock housing facilities and cattle access to water sources. Pesticides, nutrients, salt and sediments can also contaminate soil and lower the quality of water (Hooda et al. 2000; Conboy and Goss, 2001; Mapfumo et al. 2002). The phenomenon of the concentration of the livestock industry, that is, fewer farms but more livestock, has led to a large amount of manure being handled in one operation and, if handled improperly, can lead to water quality problems in surrounding water sources.

Conboy and Goss (2001) stated that rural drinking water contaminated by bacteria is more common than excessive nitrates and pesticides. Bacterial contamination has become more important in Canada and the United States during the last decade in which we have seen a number of major waterborne illness outbreaks, and since new regulatory regimes were enacted in 1985 (Johns, 2000). The concentrations of bacterial populations contained in manure are such that any input into water sources would result in levels greater than suggested in the Ontario water quality guidelines (King et al. 1994). Ontario bacterial water quality standards for drinking and recreational use are 0 and 100 organisms per 100ml for *E. coli* and fecal coliforms respectively. In a study conducted by Palmateer et al. (1989) it was concluded that there is potential for downstream farms to affect water quality several kilometers from the point source of pollution. Studying *E. coli* the authors noted that the bacteria had traveled 17km downstream in 5 days. Gerba and McLeod (1976) and Palmateer et al. (1989) both showed that bacteria survive in water and in the sediment beds of water sources very well because the sediments provide nutrients such as carbon, phosphorous, and nitrogen that support the survival of the bacteria.

Water contamination is also common in agricultural land that has been tile-drained. It was assumed that bacteria could not be transported great distances through the soil matrix but studies suggest that bacterial transport through soil macropores[8] may play a significant role in the contamination of tile drains. Studies by Dean and Foran (1992) in south-western Ontario increased concerns with respect to direct transport of bacteria to tile drains from liquid manure applications. In their field studies, they observed that tile drains became contaminated with fecal coliforms shortly after application in 9 of 12 events monitored. They noted that tillage of the soils prior to manure application appeared to disrupt macropore continuity and decrease bacterial transport to the drains. In tile drains at a depth of 75cm, Culley and Phillips (1982) observed high fecal bacteria counts for several days following fall or winter application of liquid manure. And a study by Wall (1989) indicated that bacteria in liquid manure were the

[8] Macropores are large continuous openings in field soils. They are readily visible and can extend for several meters both vertically and horizontally. Macropores can be formed by soil fauna, crop roots, cracks and fissures. (Beven and Germann, 1982)

primary source of tile water contamination. Rainfall following application also increased the bacterial concentrations. The effects that agricultural operations can have on the environment and in particular on water sources can lead to a risk to public health if not properly managed.

2.4 Manure-borne Pathogens and the Risk to Public Health

It is well documented that pathogenic bacteria can be transported in overland runoff or by subsurface infiltration in significant numbers to surface and ground water supplies. It is also well documented that these pathogens can survive in water supplies and cause illness in consumers. The prolonged survival of opportunistic pathogens introduced to water through the soil surface is especially of great concern to rural residents, the majority of whom rely on good quality potable water that is not treated (Sjogren, 1994).

Approximately 29,000 waterborne disease cases (97% bacterial) were reported during 1981-1983 in the United States with a large portion of these cases traced to the consumption of untreated groundwater (Crane, 1986 in Sjogren, 1994). Yates and Yates (1989) showed that this trend has continued, and that over half of the waterborne disease outbreaks in the United States are due to the consumption of contaminated groundwater, most of which occurred in non-municipal water systems. To be considered a waterborne disease outbreak, acute illness must affect at least two people and be epidemiologically associated with the ingestion of water (Macler and Merkle, 2000). In 1998 a 16-month old toddler living on an Ontario farm was hospitalized with an *E. coli* infection. *E. coli* was then found in 63% of the cattle on the farm. Since the child had had no direct contact with the cattle or their feces a water test was conducted. It was determined that the well water was the source of the *E. coli.* A hydrological examination of the farm yard and water well concluded that the site and design of the well were inadequate to protect against fecal contamination (Jackson et al. 1998).

Not all waterborne disease outbreaks have been associated with untreated water. As noted earlier, it is well documented that *Cryptosporidium* oocysts and *Giardia* cysts are resistant to chlorination in water treatment plants and need special attention to be controlled and that is not always given. The largest recently recorded *Cryptosporidium* outbreak occurred in Milwaukee, Wisconsin, in 1993. *Cryptosporidium* contaminated the water supply and infected nearly 400,000 consumers; half of the population. The WTP received its water from Lake Michigan and was equipped to control bacterial and viral infection but did not sufficiently kill off the *Cryptosporidium* oocysts (Robertson and Edberg, 1997). Shortly after, in 1994, the Las Vegas water supply was contaminated with *Cryptosporidium* from the Colorado River. Widespread infection ensued in the population and 19 deaths were attributed to the outbreak. In Ontario, both Collingwood and Kitchener-Waterloo have had waterborne disease outbreaks due to *Cryptosporidium,* which resulted in illness but no deaths.

One of the most serious and most closely watched waterborne disease outbreaks in Canada occurred in May 2000 in the small farming town of Walkerton, Ontario. *E. coli* O157:H7 and *Campylobacter* were isolated in one of three municipal wells after several days of heavy rain; the bacteria contaminated the water supply at high levels. It was determined that the *E. coli* O157:H7 and *Campylobacter* in cow manure from an adjacent farmer's field had washed into the poorly planned and inadequately maintained well. The contaminated water resulted in widespread illness and led to 7 deaths. It must be noted that the farmer, whose fields the manure had traveled from, was following proper best management practices as established by the Ontario Ministry of Agriculture and Food. It was also discovered that the public utility manager, Stan Koebel, was not properly trained and was not adequately fulfilling his duties as water manager.

The seriousness of the outbreak and the urge to lay blame for the tragedy by the public led to an inquiry in which all issues involved in delivering safe drinking water were examined. Justice Dennis O'Connor led the inquiry and recommended a number of steps to improve water delivery in Walkerton and in all of Ontario. It was noted that proper chlorination would have prevented the tragedy and that Stan Koebel's failure to notify authorities of the high levels of contamination in the municipal well increased the spread of the tragedy. Justice O'Connor also noted that government cutbacks at the Ontario Ministry of the Environment resulted in resources that had been spread too thin and therefore some water utilities, such as Walkerton's, were not given proper attention. O'Connor also recommended that all local health units prepare and practice emergency procedures so that all are prepared to deal with a tragedy such as this. Walkerton's public health officials were unprepared and overwhelmed which resulted in an advisory that was insufficient and did not reflect the seriousness of the situation. Some of Justice O'Connor's recommendations have been implemented including the drafting of a Safe Drinking Water Act for Ontario, and a Nutrient Management Act has been enacted by the Ontario Ministry of Agriculture and Food and the Ontario Ministry of Environment.

Another outbreak in Canada that led to an inquiry occurred in April 2001 in the city of North Battleford, Saskatchewan. In this incident, *Cryptosporidium* was the causative organism in the community-wide outbreak of gastroenteritis and led to three deaths. The City of North Battleford's surface water treatment plant is equipped with a filter unit designed to catch this parasite but it was concluded that the filter was most likely not working at the time of the outbreak. It is also important to note that the province had abandoned its inspection program of WTPs in 1993 and instead monitored bacteriological quality. The last time this WTP had been monitored was in 1991. The recommendations of the inquiry have resulted in a new province-wide water strategy in Saskatchewan. The strategy focuses on water quality standards, and improving WTP delivery as well as watershed protection. A new Watershed Authority has been created that will balance the competing land and water uses that impact water quality in various watersheds. Atwill (1995) suggested that public health officials should look for new ways to control the parasite in drinking water and suggested that the optimal strategy would be watershed protection (source protection) and land-use restrictions regarding the location and management of livestock operations within those watersheds. Watershed protection is now becoming an important means of protecting water supplies from contamination as provinces and municipalities have seen that treatment alone has not controlled contamination.

2.5 Source Water Protection

The general principle of source protection is to protect water sources from contamination from all land and water uses, and to safeguard environmental and human health and ensure a safe drinking water supply. Robertson and Edberg (1997) broke down the general principle of source water protection into four basic principles: 1) to minimize existing or potential sources of contamination within a watershed or hydraulic capture zone of a well or spring, 2) to protect the water collection system, 3) to minimize the mobility or prevalence of contaminants within the zone, and 4) to monitor for warning signs of contamination. Source protection not only includes whole watershed zones but also capture zones around springs and wells or the increased protection of water collection systems such as a pump-house. Basic strategies used in source protection may include: regulation or voluntary instruments (Johns, 2000), prohibiting land uses with a serious potential to contaminate groundwater, setting conditions under which activities may be permitted through the use of design standards

(Yanggen and Born, 1990), and utilizing minimum separation distances between land uses and water sources.

Minimizing potential sources of pollution may include limiting the number of potential water-contaminating land uses within a watershed. For example, an assessment may be conducted to determine a water source's ability to assimilate the amount of contaminants that enter it on a regular basis. Different watersheds would be assessed to handle differing amounts of inputs due to the size of the water-body, its length, or its current condition. Land use restrictions may include a maximum number of livestock per square kilometer of grassland adjacent to the water or the number of square kilometers of cropped land adjacent to the water or number of industrial sites within the watershed. This principle may be the most difficult to complete, especially in densely populated watersheds, predominantly agricultural watersheds, or any watershed that has already been largely developed. This principle can work well in and protect those watersheds that have yet to be developed.

Secondly, the protection of water collection systems does not need to include the whole watershed but zones or protected areas surrounding municipal wellheads that focus more on groundwater protection. This principle can include physical barriers such as fencing around pump-houses, berms to minimize flooding or runoff from entering the vicinity and even re-soiling of the land surrounding a wellhead to further protect it from leaching contaminants. Wellhead protection districts or zones are also being more commonly used as a means of protection, and involve regulating the existing recharge area and even future municipal wells or clusters of private wells (Yanggen and Born, 1990).

A number of zones can be created around the water supply; all with increasingly strict land uses as the zone approaches the source. Land use regulations based on zoning were first developed to prevent conflicts between incompatible land uses in the urban setting and have now been applied to rural areas to protect sensitive lands (Yanggen and Born, 1990). For example, New Brunswick has recently enacted the Wellfield Protected Areas Designation Order. This program involves a large designated protected area that is divided into three smaller zones; Zones A, B, and C. The restrictions within the zones are based on the persistence of contaminants in the environment, the different rates that they can move within the area and in the soil type found there, as well as the health risks posed by them. Zone A is the zone immediately surrounding the municipal wellhead and is the most restrictive. Within this zone septic tanks, sewer lines, petroleum products, pesticides and other similar chemicals are restricted or severely controlled. Land application and transport of manure, and the development of new septic tanks are prohibited in this zone. Zone B surrounds Zone A. In this zone bacterial risk is greatly reduced because of the increased distance from the wellhead, but the use of chemical pollutants is still very restricted. Zone C surrounds both Zones A and B and again is less stringent in its land restrictions because of the increased distance to the municipal wellhead and therefore the increased time of travel for contaminants. The Department of Natural Resources in Wisconsin also enacted a Wellhead Protection Program (WHPP) in 1993. A wellhead protection plan must be developed and approved for every municipal well that has been proposed since May 1st, 1992. Requirements of the plan include identifying the recharge area of the well, identifying the existing potential sources of contamination within a ½ mile radius of the well, the establishment of a protection area based on a hydrological study, a public education program, a water conservation program and lastly, a contingency plan for the protection of the supply under unforeseen or uncontrollable circumstances. Wellheads that were proposed and built before the May 1st, 1992 deadline were not required to have a WHPP put into place but it was recommended by the Department. Similarly in Germany, it is common practice to define three protection zones around water catchment pumps to prevent fecal pollution of aquifers (Rothmaier, 1997).

Thirdly, source protection should work to minimize the mobility and prevalence of contaminants within the zone through measures such as restricted rates of application of chemical pesticides and fertilizers onto land or through the use of minimum separation distances between the well and any land application of potential contaminants. These measures are commonly included in Best Management Practices (BMPs) or regulations for agricultural operators in the area. Logan (1990) stated that BMPs were specifically developed to deal with non-point source pollution problems such as the transport of contaminants into surface and ground water sources. Minimum separation distances, for instance, are based on the assumption that pollutants will not contaminate a water source because of the filtration that takes place in soil between the source and the wellhead (Macler and Merkle, 2000). In the new Nutrient Management Act in Ontario, there is a minimum separation distance of a two-year time of travel required between the site of land application of manure and a municipal water well. This intends to minimize the mobility and prevalence of fecal contaminants by requiring that they are spread a great enough distance, that if they were able to be transported in the soil matrix it would take approximately 2 years to reach the underground aquifer. It is assumed that within those two years, microbiological organisms would die or the number of those viable would be less than the water quality standards of Ontario and therefore too few to cause a risk of consumption.

Even though many farm operators abide by minimum separation distances, there have been cases of bacterial contamination of water supplies. Some of the guidelines may therefore be too broad for risk-free application on all soil types and topographies (Conboy and Goss, 2001). There is not a single safe setback distance that would be risk-free for all situations; which is the problem with guidelines that set homogenous regulations. In some cases, a 30m distance may not pose a threat to an aquifer, whereas in other cases a 1km separation may be needed to protect the source. The United States EPA has been reviewing a strategy for the protection of water wells from microbial contamination that involves calculating minimum separation distances based on virus mobility in the subsurface environment. The EPA assumes that if the distance is great enough to protect against virus contamination, it will also protect against less mobile contaminants such as bacteria, and protozoan parasites (Robertson and Edberg, 1997).

Monitoring for signs of contamination is not adequate in the protection of health alone because it is a reactive measure (Macler and Merkle, 2000) but combined with the previous proactive measures, monitoring can be used as a means of determining whether contamination has occurred and can signal contingency plans or alerts. There are a number of reasons why microbiological monitoring is not used on its own including: the fact that pathogenic organisms are difficult to detect and sample volumes must be large to enable detection, the detection of pathogens does not always translate into infectivity and a threat to consumers, many water labs are not equipped to monitor for all pathogens or have the resources to and lastly, definitive results can take days or weeks in a laboratory which would be too long to make timely public health decisions (Allen et al. 2000). Instead indicator organisms are monitored for signs of fecal contamination since monitoring for specific organisms is too costly and lengthy.

There has been debate over which indicator organisms are most optimal to use. Health Canada is currently rewriting its monitoring guidelines for municipal systems and is in discussion with experts as to which should be used. Commonly used indicator organisms include: total coliforms (TC), fecal coliforms (FC), fecal streptococci (FS), and *E. coli*. Edberg et al. (2000) state that there are characteristics that an indicator organism must possess to properly assess water quality, these include: being present whenever pathogens are present, it must occur in greater numbers than pathogens so that it can be easily detected, it must be hardy enough to survive the amount of time needed to be detected and it must be distributed throughout the water sample so that it can be found in random tests. Firstly, FS are not good indicators of drinking water contamination because they do not offer much information except that fecal contamination of a water source has occurred relatively recently. FS die off rather quickly compared to TC that are less sensitive than viruses and protozoan cysts to environmental stressors (Conboy and Goss, 2001). Although TC are discharged in high numbers in both human and animal feces, they are not all of fecal origin. FC bacteria are better indicators that human health may be compromised (Conboy and Goss, 2001), because their presence in water supplies indicate the presence of fecal contamination from warm-blooded animals and include *E. coli* and *Kleibsiella pneumonae*. Unfortunately these bacteria are less resistant than other pathogens, they have been detected in pristine water sources, and they may survive for extended periods. Although FC indicate fecal contamination, they do not allow determination of the source of contamination, animal or human. Instead, *E. coli* has been relied on as an indicator organism. Edberg et al. (2000) and Conboy and Goss (2001) both believe that *E. coli* is the optimal indicator for drinking water contamination because it best satisfies the criteria. *E. coli* is present in high numbers in the feces of all mammals, methods to detect it are inexpensive and simple, and it survives in a number of water sources under various pressures. Critics of using *E. coli* as an indicator organism state that the detection of *E. coli* in water samples does not necessarily specify a risk to drinking water because most strains of *E. coli* are not pathogenic. A study recently published in the *Applied and Environmental Microbiology* Journal suggests that *Salmonella* would be the best indicator because a number of studies have shown that it survives longer in a variety of water environments than *E.coli* (Winfield and Groisman, 2003). This debate will likely continue.

Source protection is also a response to a fairly new land use issue: exurban sprawl[9] or the growth of 'boomburgs' (Nelson and Sanchez, 2002; Lang and Simmons, 2002). The

[9] Where urban developments are in close proximity to agricultural operations.

exurban landscape grew faster than the urban, suburban, or rural landscapes during the 1990s in the United States (Nelson and Sanchez, 2002). This trend was also found in Canada. The rural farm population is continually becoming a smaller component of the rural population. For example, between 1986 and 1991 there were 12, 455 fewer farm residents in Ontario but 211,233 more rural residents (Caldwell, 1998). This increase was not just in small clusters of homes in the rural area but there was significant growth in the number of non-agricultural rural residents who live on properties intermingled with farm properties. As residential landowners and agricultural operators move closer, what were previously separate land uses have become intertwined and the potential for conflict has increased. Abdalla et al. (1996) state that the shrinking of the rural-urban interface has threatened the viability of farming. Well-planned source protection strategies are needed so both agricultural operators and other rural residents can avoid conflict by reducing problems and the risk of contamination by clearly defining land use restrictions and allowances. Source protection programs reduce the costs of ground and surface water contamination, not only monetarily but also by reducing the cost of conflict and division within a community as well as mitigating health costs of potential illnesses that are avoided by ensuring safe water supplies.

Chapter Three: Nutrient Management Regulations

3.1 Review of Existing Nutrient Management Policies and Strategies

A variety of strategies and policies were reviewed including Acts that discuss entire agricultural operations, and some that have a more narrow focus and deal specifically with managing agricultural waste. The areas of study have been broken down into four components: Canada, the United States, Other Countries and Ontario's new Nutrient Management Act (2002) which is reviewed individually. Appendix 3.1 summarizes the policies and strategies that have been reviewed in Canada, including the purpose of each. Appendices 3.2 and 3.3 summarize the policies and strategies reviewed in the United States and other countries, respectively.

The method of investigation for this chapter was to choose jurisdictions in Canada, the United States, and other countries that have dealt with agricultural nutrient management by creating policies or guidelines. Most jurisdictions in Canada have been reviewed. Those that are not reviewed include Newfoundland, the Yukon Territory, and Nunavut. These jurisdictions were searched but no policies relevant to this report were found, therefore they are not included. A variety of jurisdictions were reviewed in the United States. States were chosen based on the availability of the information, and the inclusion of issues that are similar to the ones focused on in Canada. The other countries that were reviewed include England, Finland, the Netherlands and Scotland. Again, these countries were chosen based on the amount of information that was available, along with the relative similarity to those issues that are covered in Canada.

Most of the jurisdictions focus their nutrient management initiatives on 3 key areas, these are:

1. Nutrient management plans/Waste management plans,
2. Storage of nutrients and,
3. Land application of nutrients

The focus was on these key areas when reviewing the various nutrient management initiatives. However, the specific regulations and practices adopted by each jurisdiction to deal with these key issues vary throughout the nutrient management policies and acts, differentiating them from each other. For example, in the case of the storage of nutrients there are a number of practices that have been adopted to minimize the potential of nutrient contamination including; facility construction requirements, minimum capacity requirements, and minimum separation distances. The review of the nutrient management acts and policies shows that there is a wide variety in the specific regulations and that consistency among policies is not high. Tables 1, 2 and 3 provide a general outline of the policies and guidelines that have been reviewed within Canada, the United States and other countries, respectively. Many of the policies involve creating nutrient or waste management plans, although some do not, many policies involve storage capacities, land application requirements during specific times of the year and on land with certain topographical characteristics.

Table 1: Jurisdictions Reviewed in Canada

Province	Legislation	Act/Reg/Guide	Date
British Columbia	Agricultural Waste Control Regulation	Reg 131/92. Part of the Waste Management Act and the Health Act.	April 1, 1992
	Drinking Water Protection Act	Act	Passed 3rd reading on April 11th 2001
Alberta	Agricultural Operations Practices Act	Regulation 267/2001	2001
	Water Act	Regulation 205/98	1998
Sask.	Agricultural Operations Act	Regulation 34/97	1995
	Establishing and Managing Livestock Operations Guidelines	Guidelines	2001
Manitoba	Livestock Manure and Mortalities Management Regulation	Regulation 42/98	March 30, 1998
	Proposed Nutrient Management Strategy for Manitoba's Surface Water	Proposed by Manitoba Conservation	May 7, 2002
Quebec	Regulation Respecting Agricultural Operations	Regulation; Environment Quebec	June 15, 2002
New Brunswick	Regulation 99-32 under the Livestock Operations Act	Regulation 99-32	May 1, 1999
	Wellfield Protected Area Designated Order under the Clean Water Act	Regulation 2000-47	October 1, 2000
	Manure Management Guidelines	Guidelines	February 1, 1997
Nova Scotia	Animal Manure and Use Guidelines	Guidelines	1991
	Siting and Management of Hog Farms in Nova Scotia	Guidelines	2001
	Green Plan	Guidelines	1994
Prince Edward Island	Guidelines for Manure Management in PEI	Guidelines	January 7, 1999
NWT	Guidelines for Agricultural Waste Management	Guidelines	May 1999

Table 2: Jurisdictions Reviewed in the United States

State	Legislation	Act/Reg/Guide	Date
Washington	Chapter 90.64 RCW: Dairy Nutrient Management Act	Act under Department of Ecology	1998
	Manure Management Guidelines for Western Washington	Guidelines funded by the Department of Ecology and the Centennial Clean Water Funds.	April 1995
Iowa	Chapter 65 of the Iowa Administrative Code: Animal Feeding Operations	Statute of Iowa Law that is monitored by the Iowa Department of Natural Resources	1999
Missouri	Guide to Animal Feeding Operations	Department of Natural Resources Guidelines	1999
Wisconsin	Chapter NR 151: Runoff Management	Department of Natural Resources	October 2002
	Chapter NR 243: Animal Feeding Operations	Department of Natural Resources	October 2002
	Guidelines for Applying Manure to Cropland and pasture in Wisconsin	Guidelines written by Fred Madison, Keith Kelling, Leonard Massie, and Laura Ward Good of the University of Wisconsin	1995
Minnesota	Minnesota Rules: Chapter 7020: Feedlot Rules	Regulations enforced by the Minnesota Pollution Control Agency	2000
Michigan	Generally Accepted Agricultural and Management Practices for Manure Management and Utilization.	Guidelines adopted by the Michigan Agriculture Commission of the Department of Agriculture.	Feb 2002
Maine	Nutrient Management Act/ Nutrient Management Rules	Maine Department of Agriculture, Food, and Rural Resources.	March 1998
Texas	Chapter 321 Subchapter B: CAFOs Rules	Texas Natural Conservation Commission	July 1999
Delaware	Delaware Nutrient Management Law (Chapter 22 of Delaware Agriculture Title III Code)	Delaware Department of Agriculture	
	Delaware Nutrient Management Program	Delaware Nutrient Management Commission of the Delaware Department of Agriculture	June 1999
Nebraska	LB 1209: The Livestock Waste Management Act	Nebraska Department of Quality	April 1998
	Title 130: Rules and Regulations Pertaining to Livestock Waste Control	Nebraska Department of Quality	1972, and updated anytime new livestock-legislation is passed.

Table 3: Other Countries Reviewed

Country	Legislation Name	Act/Reg/Guide	Date
England	The Code of Practice for the Prevention and Control of Salmonella on Pig Farms	Guideline under the DEFRA	1999
	The Code of Good Agricultural Practice for the Production of Water.	A Statutory Code under Section 97 of the Water Resources Act 1991 under DEFRA.	1998
Finland	Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters. Pursuant to Section 11 of the Environmental Protection Act.	Law under the Ministry of the Environment.	Nov 15 2000
Netherlands	Dutch Approach to Reduce the Mineral Surplus and Ammonia Volatilization	Law	1999
Scotland	Prevention of Environmental Pollution from Agricultural Activity	Law under the Scottish Office Agriculture Environment and Fisheries Department	1997
	The Control of Pollution (Silage, Slurry, and Agricultural Fuel Oil) (Scotland) Regulations 2001	A Scottish Statutory Instrument	July 1, 2001

3.1.1 Nutrient Management Plans/Waste Management Plans

Although pathogens and nutrients are natural components of an ecosystem, human development, industrialization, agricultural activity, and the population of watersheds, all increase the loading of these materials into the water. Where increased loadings occur, pathogens and nutrients exist in such high concentrations that they effectively become contaminants that can cause significant water quality problems. Increased loadings can occur when manure and fertilizers are applied to land without consideration of the amount being distributed. These increased loadings have created a policy response by government. Policies are created first, before nutrient management plans, in an attempt by governments to respond to an ungoverned situation that poses a threat to health, and within the policies nutrient management plans are used as instruments to protect water quality through nutrient calculation.

A nutrient management plan (NMP) is a process to match the nutrients available in manure and commercial fertilizer to nutrients required by the crop, thereby preventing the buildup of nutrients in soils but at the same time improving crop yield. A sound NMP identifies manure application rates that meet crop nutrient needs, termed the agronomic rate, therefore minimizing the need to use additional fertilizers. Application of manure at agronomic rates minimizes the potential for nutrients to move out of the crops' root zone and maximizes the manure's nutrient value to the landowner.

Well-designed plans will also account for local and on-site conditions that could affect the fate of manure once it is field-applied, such as soil type, topography and weather patterns. Potential environmental impacts are minimized through the use of adjusted application rates and management practices that are appropriate for the given crop and local conditions.

Nutrient management acts and policies set the stage for developing nutrient management plans; these plans place the responsibility for applying and controlling nutrients on individual farm operators. A review of agricultural policies and drinking water protection policies across the globe shows that most jurisdictions have required, or strongly recommended, that nutrient management plans (NMP), also known as waste management plans (WMP), be filed by agricultural operators.

3.1.1.1 Canadian Nutrient Management Plans/Waste Management Plans

The North West Territory is the only jurisdiction reviewed that did not have a strategy similar to a NMP in place. British Columbia's Ministry of Agriculture, Food and Fisheries (BCMAFF) is the only agriculture ministry to not require or explain how to complete a NMP. The British Columbia Agricultural Waste Control Regulation (1992) does state that waste must not be applied to land at rates that exceed the amount required for crop growth but this is a broad requirement that lacks any other specifics to guide operators. The NMP Guide for British Columbia suggests what should be included in a plan but gives no instruction or further information on how to determine rates of application, nutrient requirements, or any other calculation that would be needed.

The lack of a required NMP may change quickly when the British Columbia Drinking Water Protection Act is enforced[10]. The BC Drinking Water Protection Act allows the Health Services minister to designate an area for the purpose of developing a drinking water protection plan (DWPP) if the minister considers that a plan will assist in addressing or preventing threats to drinking water. These threats can include an overload of nutrients from agricultural operations or municipal sewage systems. Once an area has been designated, nutrient loadings will be monitored, therefore, some agricultural operators may eventually have

[10] The BC Drinking Water Protection Act passed its third reading on April 11th 2001; it has received Royal Assent but is not yet enforced.

to develop a NMP in order that these nutrients can be calculated into the overall NMP for the designated area.

The province of Manitoba is similar to British Columbia in that the Livestock Manure and Mortalities Management Regulation (1998) requires operators that house more than 400 animal units to apply livestock manure to land in accordance with a NMP that has been registered. But no information is given regarding what is required in order to approve the NMP. Again, this requirement may be given higher priority when Manitoba's proposed Nutrient Management Strategy for Surface Water (2002) is implemented. This strategy acts in a similar fashion to BC's Drinking Water Protection Plan in that regional boundaries will be defined within which each area within a set of boundaries will develop its own drinking water protection plan. These plans will depend on each region's current nutrient status and land uses, therefore in areas of high nutrient release, more stringent plans may come into effect that will pertain to all industries that handle, produce or transport materials that contain nutrients, including agricultural operations.

The Alberta Agricultural Operations Practices Act (2001) and the Quebec Regulation Respecting Agricultural Operations (2002) have similar NMP requirements. Both require a comprehensive NMP for the application of livestock manure on agricultural soil, although Alberta's NMP is only required if requested by Natural Resources Conservation Board (NRCB) inspectors. In preparing a NMP for the NRCB in Alberta, operators must have their soil tested every three years to determine extractable nitrogen and phosphate levels, and soil salinity and texture. Nitrogen is used as the determining nutrient and specified nitrate-nitrogen levels are not to be exceeded. The NMP is comprehensive in that it takes into account soil type, manure type, livestock type, and number of livestock. The NMP produces a final land-based requirement for a certain type of crop based on the soil type, livestock type and manure type of each individual farm. Quebec's Regulation and NMP requirement goes one step further and requires a plan for all fertilizing substances, including bought fertilizers and composts, not only animal manure. These plans must be approved by a government agronomist and must include information such as: amount applied of each fertilizing substance on each parcel of land, method of spreading, and the duration and dates of spreading. Spreading techniques and timing of application can alter the amount of nutrients that are available to crops therefore this information is important in NMP calculations.

The nutrient management plans discussed above only require plans for the calculation of the nutrient levels in soils and manure. Both New Brunswick and Saskatchewan require not only NMP for the application of nutrients on land but also waste management plans that describe storage, transport and the management of dead animals. These practices are also important in nutrient management because, if not carried out properly, they can result in nutrient and pathogen contamination. New Brunswick Regulation 99-32 under the Livestock Operations Act (1999) requires a NMP and a manure system description before renewal of or approval of a Livestock Operators License will be granted. Appendix 3.4 lists the complete requirements for both the plan and the description. The Saskatchewan Agricultural Operations Act (1995) requires much the same as New Brunswick, a waste storage plan, waste management plan for land utilization, and a waste management plan for dead animal management, although these plans are only required of intensive livestock operators[11].Waste storage plans involve specific construction requirements for various types of storage facilities such as an earthen storage area, holding pond, and liquid manure storage tank. The land utilization waste management plans must provide details on the annual volume of manure produced, the estimated amount of nitrogen, phosphate and potassium in the manure, as well as manure type, application type, expected crop nutrient requirements, land area available and any plans for manure other than land utilization. Dead animals also contain nutrients and pathogens and therefore must be carefully discarded; these plans must calculate the expected animal deaths per year and discuss the method of disposal chosen.

Nova Scotia has developed a relatively comprehensive guideline for the completion of NMP through its Canada-Nova Scotia Agreement on the Agriculture Component of the Green Plan (1994). There are two documents required including a nutrient management job sheet that describes the allocation of manure resources on the participating farm on a field-by-field basis, and a report summarizing annual manure production and use and the overall farm manure surplus or deficit. Manure samples must be taken to determine the macronutrients, micronutrients, and secondary nutrients that are available for plant take-up. These requirements deal strictly with manure utilization and not storage or transport.

[11] Intensive Livestock Operators require management plans when their operation: a) contains an earthen manure storage area or lagoon; b) involves the rearing, confinement or feeding of 300 or more animal units for more than 10 days in any 30-day period; or c) subject to b), involves the rearing, confinement or feeding of more than 20 animal units but less than 300 units, for more than 10 days in any 30-day period, and any part of which is within 300m of surface water or 30m of a domestic well not controlled by the person who operates the ILO.

3.1.1.2 United States Nutrient Management Plans/Waste Management Plans

All jurisdictions reviewed require a form of nutrient management plan. Washington, Wisconsin and Nebraska all have Nutrient or Waste Management Acts that require NMPs and separate guidelines or rules for specific regulations. Most management plans in these jurisdictions require the same information; calculations of nutrient or manure production levels and crop requirements, collection, storage and treatment methods, land application rates, methods and timing. Soil erosion must also be addressed in most jurisdictions, although in Wisconsin's Runoff Management Rules (2002), all cropped fields must meet a Tolerable Soil Erosion Rate[12] and these calculations must be included in the plan. Michigan on the other hand, addresses erosion by restricting livestock from waterways in controlled access areas and requires stream bank management to reduce sediment accumulation in waterways.

Based on risk of application calculated in the Nebraska Livestock Waste Management Act (1998), operators my be required to test groundwater biannually to determine nutrient levels and therefore determine if management practices are effective at keeping nutrients out of the water supply. Considering this is one of the overall goals of most of the Acts being reviewed, this proactive requirement should be utilized by more jurisdictions, especially since only nutrient management plans in Washington and Texas are subject to inspection programs. This requirement would allow operators to detect contamination and track levels over the season and over the years, results would also help to determine whether their plans should be revised for improvement.

The inspection program in Washington tracks nitrogen levels in groundwater, when nitrogen has been identified on an operation, an end-of-season nitrate-N soil sample and analysis must be completed. This also must be completed on operations where combined precipitation and irrigation are greater than 25 inches (63.5 centimeters). Otherwise, soil tests in Washington must be taken every 3 years for perennial crops and annually for annual crops.

In Delaware, two types of plans are required. Those operations that contain animals must develop an Animal Waste Plan, and those operations that only apply nutrients to land, such as cash-cropping operations, must develop Nutrient Management Plans. Operators that house animals and apply nutrients to land must develop both. These plans must include manure

[12] Tolerable soil loss is defined as the maximum rate of erosion, in tons per acre per year, allowable for particular soils and site conditions that will be maintain soil productivity.

production calculations, nutrient calculations, crop requirements, collection, storage and transfer methods, and utilization plans for manure with respect to each field within the operation.

Maine's nutrient management plans do not require information regarding operations; instead the plans focus strictly on crop requirements and nutrient calculations during land application. This NMP does not require information such as storage, transfer or treatment methods but simply the contents of the waste, how and where it will be applied. Maine's plans must also include soil erosion provisions.

3.1.1.3 Other Nutrient Management Plans/Waste Management Plans

Both Finland's Decree on the Restriction of Discharge of Nitrate from Agriculture into Waters (2000) and Scotland's Control of Pollution Regulations for Silage, Slurry and Agricultural Fuel Oil (2001) do not address or require nutrient or waste management plans. On the other hand, nutrient management plans are the key to the Netherlands Manure and Fertilizer Policy (1999). The Dutch landscape is stressed due to the intensity of livestock production in the country and eutrophication is a serious problem in its waters, therefore the Netherlands Manure and Fertilizer Policy (1999) is largely based on the Minerals Accounting System (MINAS) (Netherlands Ministry of Agriculture, 2001). This system is based on the amount of phosphate and nitrate that each agricultural operation receives and applies throughout the season. Agricultural operators work to equalize the amount of inputs and outputs of nutrients, the surplus of nutrients used is the difference. Therefore the volume of manure spread on the land should be equal to the uptake requirements of the crops. If farmers have a greater amount of manure than they can handle, they must find surplus land or reduce the number of livestock they house. All inputs and outputs must be recorded. Some mineral losses are allowed, but if larger surpluses are accrued, then operators are fined based on the extent of the surplus. All operations are accounted for in this system including storage, transport, treatment and land application. Contingency plans are required for the next growing season and must be followed if levies have been charged.

In the England Code of Good Agricultural Practice for the Production of Water (1998), waste management plans (WMP) are also required. One of the objectives of these WMP is to reduce the risk of transfer of pathogens to livestock. This Code is one of the few policies reviewed that addresses pathogens and their control. These plans must include categorizing land areas based on their risk of water pollution and matching land area to the amount of nutrients in the wastes. These plans must also address storage and handling. Operators must have contingency plans in place including where to obtain needed emergency equipment if it is discovered that contamination has occurred.

Farm waste management plans (FWMP) in the Scotland Prevention of Environmental Pollution from Agricultural Activity policy (1997) involve all aspects of manure handling to establish the quantities of waste produced and safe methods[13] of collection, transport, storage, treatment and land application. A FWMP must include four steps: identifying the waste production schedule, preparing a land availability schedule, matching the waste production to land availability and calculating the amount of storage required. Identifying the production schedule involves the type, quantity, and nutrient content of the wastes produced in an operation. The land availability schedule involves calculations based on type of crops, land suitability, and proximity of watercourses, sensitive habitats and other sensitive features. A FWMP must include any imported or exported farm waste.

3.1.1.4 Nutrient Management Plans/Waste Management Plans Conclusions

Based on the review of the requirements of nutrient management plans, the primary objective of nutrient management plans is to calculate nutrient loadings onto agricultural land. Some nutrient management plans simply require land application calculations whereas others require handling and storage plans as well.

Overall, of the jurisdictions that require NMPs, only one addresses the issue of pathogens. Herd infection rates, shedding rates and pathogen loads in waste once applied to land are nearly impossible to calculate and therefore it is ineffective to attempt to address pathogens in this manner. However, pathogens could be addressed in handling and storage plans as they are in England's Code of Good Agricultural Practice for the Production of Water (1998). This policy addresses pathogens with respect to manure handling to avoid the infection of livestock herds. The waste management plan required under the Code is therefore the most restrictive and effective with respect to pathogen control. The nutrient management plans within the other policies fail to address pathogens and this could lead to inadequately controlled pathogens and contamination by focusing solely on nitrogen and phosphorus loads.

[13] Safe methods based on nutrient loads.

3.1.2 Storage of Manure

A properly designed manure handling system is convenient for the operator, maintains the health and safety of humans and animals, conserves nutrients in manure while allowing pathogen die-off, minimizes handling costs and protects the environment (Manure Management Task Group, 1991). Manure storage systems are functionally similar but there is no ultimately optimal system in practice because storage systems largely depend on the type of manure that is used: solid, semi-solid, or liquid, and the operations on that farm. The tables in Appendices 3.5, 3.6 and 3.7 show the detailed information about storage regulations in each jurisdiction for Canada, United States and the other countries, respectively.

3.1.2.1 Storage in Canada

Both the British Columbia Agricultural Waste Control Regulations (1992) and the Alberta Agricultural Operations Practices Act (2001) do not require the approval of nutrient or waste management plans. However, they do require the largest amount of minimum capacity from storage facilities in Canada: 270 days. In British Columbia, this may be due to the wet climate of the province and to ensure that manure can be stored until the saturated soil conditions that are found in wet climates are dissipated. When it comes to minimum separation distances, the two policies differ greatly. In the case of the BC Agricultural Waste Control Regulations (1992), all storage types, with the exception of field storage, have minimum separation distances (MSDs) of 15m to any watercourse and 30m to any wellhead or water source for domestic use. Whereas the Alberta Operations Practices Act (2001), the MSDs are much greater, there is a required base separation of 30m from a watercourse, 100m from a wellhead, and 150m from the nearest residence.

The BC Waste Control Regulations (1992) allow field storage for two weeks or up to nine months if the field pile is greater than 30m from any watercourse. The field pile and watercourse must also be separated by a berm that creates protection of the water body. These regulations are the only regulations in the country to mention the use of under-pen storage, a fairly new type of storage management for solid manure. These slatted flooring systems are normally used for liquid manure and are particularly prevalent for hog finishing barns, beef finishing barns, and some dairy farms (Mussell, 2002). Solid manure versions of these are being developed for hogs in which straw is used to compost the manure. The regulations also state that certain areas of the province that receive a greater amount of rainfall, such as the

Fraser Valley and Vancouver Island, need to cover field-stored manure piles to prevent runoff. The Alberta Agricultural Operations Act (2001) also takes into account some non-normal conditions: the construction of storage facilities must take into account the flooding that can occur in a 1:25 year flood. And lastly, a catch basin must have a storage capacity that can accommodate at least one day maximum of rain that has a 1:30 year probability as calculated based on the county average.

The Saskatchewan Agricultural Operations Act (1995) requires a very detailed storage plan that must include specific details that follow normally accepted agricultural practices that are in the Saskatchewan Livestock Operations Guidelines (2001). No other requirements are stated in the regulations but a ministry official must approve all plans. For more clarity, the plan requirements should accompany the document requiring a plan to be written. Instead only guidelines are found in the Saskatchewan Livestock Operations Guidelines document: recommendations are given on construction and type of storage that should be utilized for both liquid and solid manure. There is a required minimum storage capacity of six months, but 360 days is recommended.

Manitoba's Livestock Manure and Mortalities Management Regulation (1998) also requires a storage plan but includes the specific regulations that plans must contain. Operators of a facility that houses more than 400 animal units must have a plan registered with the director of the ministry. Moreover, in the opinion of the director, any facility with less than 400 animal units may also require a plan if it is thought that the operation is in jeopardy of contaminating nearby water bodies or wellheads. This regulation is consistent in its minimum setback distances; all types of storage facilities must be sited at least 100m away from any water-body or well. This includes field storage of solid manure. Manitoba's regulators may have taken a different approach to the regulations than any of the other provinces by keeping MSDs the same and creating construction restrictions based on soil type at that location. There is also a restriction in siting a storage facility within the boundaries of the 100-year flood plain elevation.

The Quebec Regulations Respecting Agricultural Operations (2002) have differing minimum setback distances for varying types of storage facilities. Constructed watertight facilities have less stringent MSDs than field storage piles that should remain at a greater distance because of the lack of constraints that could contain the manure from running off into nearby watercourses. These regulations have a minimum capacity requirement of 180 days in order to have enough storage capacity to make it through the winter months.

In examining the guidelines and regulations in New Brunswick, the minimum separation distances in the guidelines were much more rigorous than the regulations. In the New Brunswick Livestock Operations Act Regulation 99-32 (1999), operators must abide by a MSD formula when siting storage facilities. The formula takes into account the manure type, livestock type, and manure storage type[14]. Although this formula gives the impression that it is scientifically calculated, the livestock factor appears to take into account the odour strength of the type of manure as most important rather than the amount of manure that that type of livestock would produce on average. The 'all other livestock' category must include dairy and beef cows and in terms of abundance of manure and prevalence of pathogens, this type of manure should be a larger factor in the equation than poultry and swine manure. The minimum capacity requirement in Regulation 99-32 is 210 days after November 1st, therefore allowing operators to be able to store manure through the winter so that winter application is unnecessary. The minimum separation distances (MSD) calculated in the New Brunswick Manure Management Guidelines[15] are much more detailed than the MSD formula in Regulation 99-32. This formula is a function of four factors: base distance as a function of animal units, an expansion factor, a manure system factor, and livestock type factor. Although this formula is more detailed, it again seems to be focused on odour rather than environmental protection. This appears to be the case because watercourses, property lines, and highways have constant separation distances of 100m, 20m and 20m respectively, whereas the formula only applies to such areas as neighbouring dwellings, residences, and commercially or recreationally zoned areas. Similarly, there is a storage capacity requirement of 210 days after November 1st.

Nova Scotia's manure management requirements are simply guidelines but recommend a very detailed nutrient management plan that must be approved by an officer. The Nova Scotia Animal Manure and Use Guidelines (1991) require that operators obtain a manure handling system design from the Nova Scotia Department of Agriculture and Marketing Extension. The system plan incorporates farm resource considerations including economics,

[14] See Appendix 3.8 for the complete formula.
[15] See Appendix 3.9 for the complete formula.

manpower, equipment, existing structures, animal populations, site characteristics and storage capacity. The guidelines do require a base distance between storage facilities and water bodies or wells of 100m. The minimum storage capacity is similar to most other provinces at seven months. Hog operators can look to more specific guidelines for the management of their manure. The MSDs from storage facilities are found in Appendix 3.10, and it is clear that these minimum separation distances are for the purpose of odour control. Again, watercourse and wellhead MSDs remain constant at 100m regardless of the size of operation but MSDs increase with size of operation for off-farm dwellings and non-farm developments. The minimum storage capacity is the same at 210 days.

Prince Edward Island also relies on guidelines to manage manure across the province but is very detailed in its recommendations due to the fact that 100% of PEI drinking water supplies come from ground water (Black, 2002). It is also a rural agricultural province but with very little land base therefore the proper management of manure is essential. Minimum separation distances for the siting of manure storage facilities to nearby wells are fundamental to the guidelines and take into account county specific topography and hydrogeology concerns. The guidelines use a soil map survey and address geographical concerns such as shallow bedrock, and seasonally high water tables. These concerns are weighed and given a multiplication factor such as 1.5 or 2 depending on their severity and are then multiplied by the base distance of 90m. Some counties in the province do not have siting concerns, while other counties must be investigated on a site specific basis. These regulations are the only ones reviewed that closely resemble watershed source protection areas, in which each county is unique. Vegetated filter strips placed between storage facilities and watercourses are also highly recommended. Vegetated filter strips are more effective in retarding the movement of nutrients rather than pathogens. Because of the small size of pathogenic organisms these strips are not as effective in catching the pathogens and blocking them from entering into bodies of water (Dorner, 2002). Again, the recommended minimum storage capacity in a constructed facility is 210 days from November 1st. If operators are utilizing solid manure and field storage is an option, then 60 days accumulation is sufficient.

One of the key recommendations in the North West Territory Guidelines for Agricultural Waste (1999) is the holding capacity of manure storage facilities. Due to the longer winter season and in order to avoid spreading on frozen or snow-covered ground, these guidelines have one of the longest requirements at 240 days. The minimum setback distance for siting a manure storage facility must be 100m to both watercourses and wells. The separation distances of storage facilities from populations are a function of the human population and the number of animal units on the operation[16]. The distances are extended if the operation utilizes an open air liquid manure storage facility.

3.1.2.2 Storage in United States

Manure storage facilities in the United States are regulated in the same manner as in Canada, with construction requirements, minimum separation distances from sensitive areas and storage capacity requirements.

In Maine, under the Nutrient Management Law and Nutrient Management Rules (1998), the location of storage facilities is very site specific and the only absolute MSD is that they must be sited at least 30.48m from any domestic wells. Washington and Iowa are the only states that address separation distances of storage facilities to watercourses; this is very different from the policies in Canada, where most require a MSD to a watercourse. Washington requires a MSD of 91.44m, whereas Iowa distinguishes between major and minor watercourses with separation distances of 152.4m and 60.92m, respectively.

Many jurisdictions in the United States distinguish between private and public wells, which again is different than most of the Canadian policies reviewed. Minimum separation distances are always greater for public wells where, if contamination occurred, a greater number of people would be exposed. Both Minnesota and Nebraska require 304.8m between a public well and a constructed storage facility and only 30.48m from a private well. Iowa on the other hand, distinguishes the differences in the construction of the wells. A deep well is defined as one that is located and constructed so that there is a low-permeability layer of soil at least 1.5m thick surrounding it that extends as deep as 7m, and a shallow well is not surrounded by this continuous layer. A formed storage facility must be sited at least 30.48m from a deep well and 60.96m from a shallow well. Other separation distances to private and public wells can be found in Appendix 3.12. Appendix 3.12 also shows MSDs of storage structures to residences, businesses and public use areas. These MSDs are based on the type of structure, whether covered, confined, or earthen, and the type and weight capacity of the

[16] See Appendix 3.11: Separation Requirements of Storage Facilities from Populations (m) in the NWT.

livestock on that operation. These factors suggest that the MSDs are calculated based on odour control and not on risk of contamination. Missouri's Guide to Animal Feeding Operations (1999) also separates storage facilities from residential areas based on the number of livestock housed, as numbers increase so does the MSD. Other siting requirements found in these policies include location of facility above the seasonal high water level of at least 1.22m in both Missouri and Nebraska. Distance to bedrock is only addressed in Iowa's Chapter 65 (1999) with respect to earthen storage structures and requires a distance of 3m. Iowa is the only state that has greater MSDs to sensitive areas for earthen storage facilities than constructed facilities, see Appendix 3.12. Iowa also requires a greater storage capacity at 420 days. Capacity requirements for constructed storage facilities are fairly consistent throughout these regulations at 180 days. Wisconsin's Animal Feeding Operations Rules (2002) do not specify capacity; capacity must be approved in the Manure Management Plan and is specific to each operation.

Due to its exposure to the elements and greater risk to runoff, field storage usually requires individual site assessment to minimize risk of contamination. Field storage is allowed but restricted in most jurisdictions. For example, in Wisconsin's Animal Feeding Operations Rules (2002), operators must have written approval to store waste in fields, this may be based on site and manure characteristics or may only be permitted in extreme circumstances. In Minnesota, field storage is prohibited on land with a slope greater than 6% or where the soil texture is coarser than sandy loam in order to avoid leaching and runoff. Under Wisconsin's Runoff Management Rules (2002), field storage is prohibited in defined Water Quality Management Areas[17].

Non-normal conditions, such as weather, topography, management styles, or accidents are often factors in contamination events, unfortunately non-normal events are also difficult to regulate and prepare for. Under Iowa's Animal Feeding Operations (1999), the state has

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[17] Water Quality Management Area: the area within 1000ft from the ordinary high water mark of navigable waters that consist of a lake, pond, or flowage, or a site that is susceptible to groundwater contamination. A site susceptible to groundwater contamination means 1) an area within 250ft of a private well, 2) an area within 1000ft of a municipal well, 3) an area within 300 feet upslope or 100 feet downslope of karst features, 4) a channel with a cross-sectional area equal to or greater than 3 square feet that flows to a karst feature, 5) an area where the soil depth to groundwater or bedrock is less than 2 ft, and 6) an area where the soil does not exhibit one of the following a) at least a 2-foot soil layer with 40% fines or greater above groundwater and bedrock, b) at least a 3-foot soil layer with 20% fines or greater above groundwater or bedrock, and c) at least a 5-foot soil layer with 10% fines or greater above groundwater and bedrock.

protected against any abnormal conditions by including a clause stating that if topography, management procedures or other factors indicate a higher (or lesser) level of risk of water pollution then the department may establish different requirements for that operation. Similarly, Western Washington's Guidelines for Manure Management (1995) suggest that an extra month's storage capacity is recommended when abnormal weather conditions prevail and land application of manure is halted. These clauses on non-normal conditions are unique and can aid in minimizing risk of pollution.

3.1.2.3 Storage in Other Countries

In the Code of Good Agricultural Practice for the Production of Water in England (1998), pathogens are addressed. Specifically, the Code states that on operations where *Cryptosporidium* has been diagnosed, slurries should be stored for as long as possible to kill as many as possible and farm yard manure should be stored for at least 60 days before being utilized on land. The location of storage facilities with respect to domestic water supplies is not addressed; the facility must be located at least 10m from a watercourse, as well as 10m from a drain field. Recommended capacity of the storage facility is only 120 days; the shortest capacity of all nutrient management policies reviewed. Treatment[18] is recommended to further kill pathogens before land application as well as to decrease the smell and decrease BOD levels of the waste.

Opposite of England's Code of Practice, Finland's Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters (2000) requires the largest storage capacity at 360 days accumulation. In determining storage capacity, small outdoor yards and housing facilities with litter bedding should also be considered, along with the larger tanks and lagoons. This capacity can be reduced if the operator obtains a permit showing that a portion of the manure is being transferred to another user. Field storage in Finland is only permitted after manure has been composted for at least 90 days and has a dry matter content of at least 30%, this will reduce the risk of runoff and leaching. Field piles must be placed on top of a 15cm thick peat or mud layer to further reduce the leaching potential and must be covered with a tarp or a peat layer to avoid runoff from rainfall and evaporation and to contain odour, and cannot be located in the same place each year. Other storage facilities must be sited at least 10m from

[18] Treatment methods include solids separation, anaerobic digestion, and aerobic digestion.

any bodies of water; this MSD is consistent with the MSDs in the other countries for constructed storage facilities.

In the exact manner as the England Code of Practice, the PEPFAA program in Scotland (1997) addresses specific measures in the case of *Cryptosporidium* diagnosis within an agricultural operation. To reduce *Cryptosporidium* contamination or spread within the herd, storage of waste should be prolonged, slurries should be stored as long as possible, and storage of solid manure should be at least 60 days. Although unlike the English Code, location of storage facilities with respect to wells and springs must be at least 50m and as far away as possible from residences on and off the farm property. MSDs to watercourses and field drains are consistent with other countries at 10m. Treatment of waste while in storage is recommended based on type of waste and individual farm operations. Mechanical separation, anaerobic digestion, aerobic treatment, the acidification of slurry, the addition of nitrification inhibitors, and composting are all recommended, see Appendix 3.13.

Storage requirements in the Netherlands Manure and Fertilizer Policy (1999) are not addressed. 180 days storage capacity is required to get through the winter months and is consistent with Scotland's capacity requirements.

3.1.2.4 Storage Conclusions

Few policies address pathogens with respect to storage requirements. England's Code of Good Agricultural Practice for the Production of Water (1998) and Scotland's PEPFAA program (1997) do address pathogens with respect to a *Cryptosporidium* diagnosis on the farm. Certain storage requirements are imposed in order to render the *Cryptosporidium* nonviable prior to land application of the waste. Considering pathogen infection can go undetected within a herd, wastes should always be assumed to carry pathogenic materials at all times and these storage requirements should be imposed on all wastes to reduce the risk of contamination once applied to land.

It should be noted that treatment of manure in storage has also been overlooked in these policies and guidelines. Treatments such as anaerobic digestion or aeration have been shown to be effective at reducing pathogen levels in livestock waste. In the policies that do address treatment, such as Michigan's Generally Accepted Agriculture and Management Practices (2002), treatment methods are described but none are required or recommended.

It is difficult to determine whether these storage regulations will help to control pathogen contamination because the type of storage method utilized is at the discretion of the operators. The type of storage method used could reduce pathogen loads in waste, such as lagoons, composting or batch storage, but since methods are not known the pathogen reduction potential of these regulations is uncertain.

3.1.3 Land Application of Manure

Economically and environmentally the best method of utilizing manure is to spread it on the land, and the nutrient management guidelines that have been reviewed recommend it. If applied properly and in the correct amounts, manure not only provides nutrients but also acts as a soil amendment (Manure Management Task Group, 1991). The application recommendations are made to ensure that manure or runoff does not create a risk to the environment or an inappropriate disturbance, and/or enter a common body of water by leaving the land on which the manure is applied (Amrani, 2002). Developing and following proper manure management plans ensures that the components in manure are applied to agricultural land to meet crop nutrient requirements. Land application of manure focuses on four major points: setback distances, winter spreading, incorporation of manure, and rates of application. The tables in Appendices 3.14, 3.15 and 3.16 show the detailed information about land application regulations in each jurisdiction that is discussed in the following sections for Canada, United States and the other countries, respectively.

3.1.3.1 Land Application of Manure in Canada

In the British Columbia Agricultural Waste Control Regulation (1992) no specific setback distances are required, instead there are a broad set of conditions that are unfavorable for application, including winter field-application, on areas having standing water, in diverting winds and on saturated soils. These conditions are very broad and it would be difficult to determine the correct spreading times and situations if these were the only constraints given. These regulations do not discuss incorporation or tillage methods. Application rates are not defined; this regulation simply states not to exceed the amount of nutrients required for crop growth.

The Alberta Agricultural Operations Practices Act (2001) is much more detailed in its requirements regarding land application of manure compared to the BC Regulation. MSDs are given for frozen or snow-covered land and for forage or direct seeded crop based on a function of the slope of the land[19]. If these MSDs are followed, winter application is allowed. Other setbacks include 30m from a well and 30m from a common body of water, if subsurface injection is used only a 10m separation from a common body of water is required. Soil testing is required every three years if operators apply more than 300 tonnes of manure annually. Although both setbacks and limits must be followed, incorporation must also take place within 48 hours of application, except in the winter months when the ground is frozen or on forage or direct seeded crops.

The Saskatchewan Agricultural Operations Act (1995) requires a land application plan that must include specific details regarding normally accepted agricultural practices. These best management practices are found in the Saskatchewan Livestock Operations Guidelines (2001). The Guidelines have established MSDs based on application and tillage methods to minimize both public nuisance and water contamination[20]. Provincial regulations do not specifically prohibit winter spreading; however it is not a recommended practice. Incorporation is also strongly recommended within 24 hours to minimize the risk of manure being washed away in a rainfall and the potential of neighbouring complaints. Minimizing excessive nutrient losses by targeting application rates to meet crop requirements is mentioned but not required and calculation instructions are not given.

The Manitoba Livestock Manure and Mortalities Management Regulation (1998) gives no specific MSDs, instead the regulation uses land characteristics to determine if spreading is appropriate but these land characteristics, including meteorological, topographical or soil conditions, are broad and do not define any specifics for the operator. No operator in Manitoba is allowed to spread manure between November 10th of one year and April 15th of the following year except in accordance with the MSDs shown in Appendix 3.19. Incorporation and methods of application are not discussed in the regulation. No testing of the soil or manure is required but rates of nitrate-nitrogen must not exceed given ratios that are a function of the type of crop and the type of manure.

In the Quebec Regulation Respecting Agricultural Operations (2002) operators require a land application plan if the land-base to be manured is greater than 15 hectares. Minimum

[19] See Appendix 3.17: MSDs for the Application of Manure in the Alberta Agricultural Operations Practices Act.
[20] See Appendix 3.18: MSDs for the Application of Manure in Saskatchewan.

separation distances of 30m are given for land application between both watercourses and wells. Quebec also has a MSD of 1m for the distance between manure-applied fields and ditches that could drain into other bodies of water. Winter application is prohibited for the 6 months between October 1st and March 31st. Spreading is also prohibited using sprinklers or liquid manure cannons. The spreading of manure must adhere to the fertilization limits according to the "Phosphated Fertilization Standard" in Quebec to minimize the risk of soil and water contamination.

The New Brunswick Livestock Operations Act Regulation 99-32 (1999) does not discuss specific land application requirements and only touches on them in the requirements for the nutrient management plans. The New Brunswick Manure Management Guidelines (1997) are more comprehensive in dealing with this issue. Setback distances from a watercourse depend on the type of manure and whether incorporation will take place. Liquid manure cannot be spread within 300m of watercourses and solid manure cannot be spread less than 30m from the bank of a watercourse unless incorporation occurs within one day. A 75m buffer from manure-applied land protects domestic water supplies and wellheads. Incorporation of manure within 24 hours is only required during the summer months when manure is spread within 200m of a residence. Winter application is strongly unadvised by the guidelines and where runoff is a risk, manure should not be spread if rain is expected within 24 hours at anytime of the year. Applications rates are not to exceed the nitrogen requirements of the crops in order to minimize excess nitrogen in the soil.

The Nova Scotia Guidelines for the Management and Use of Animal Manure (1991) and the Siting and Management of Hog Farms Guidelines (2001) both have very similar land application requirements. Appendix 3.20 shows that MSDs to watercourses are a function of the slope of the land and soil type, as well as dug and drilled wells. Incorporation is also recommended as soon as possible to minimize the risk of contamination even further. Winter spreading is strongly ill advised in order to avoid runoff and due to the fact that incorporation in the winter is difficult if not impossible. Both documents require that both nitrogen and phosphorus rates are monitored and do not exceed the requirements of the crop.

In Prince Edward Island there is not a lot of extra arable land on the island therefore many livestock operators do not have a sufficient land base to apply all of the manure that their operations produce. The Manure Management Guidelines (1999) require spreading agreements with landowners who do not generate manure but only cash crop. Appendix 3.21 shows the recommended setback distances for spreading manure in PEI. These MSDs reveal that the other major industry in PEI is tourism and that these two industries must cooperate so that they can prosper together. Unfortunately, these MSDs do not exhibit much proof of being scientifically based, which would ensure minimal contamination. Again, winter application is not recommended. These guidelines require that the application rate of manure should not exceed the amount necessary to meet the crop nitrogen requirements. A choice between two methods is presented, one in which an estimated land base area using typical nutrient production rates is used or a more detailed site-specific method based on manure and soil samples is the preferred choice.

3.1.3.2 Land Application of Manure in United States

In the state of Washington, the Dairy Nutrient Management Act (1998) and the Manure Management Guidelines for Western Washington (1995) have been reviewed. These two pieces of legislation fit well together because the Act does not identify specific management regulations, whereas the Guidelines provide recommended practices so that operators may stay in compliance with the Act. Specifically, the Management Act simply states that priority land application should be located on fields with gentle slopes located away from watercourses. When application is needed on greater sloping fields, other protection measures must be taken. However, the Washington Guidelines give specific MSDs form sensitive areas with which to comply, for example, application from watercourses and ditches should be between 3 and 9m, and from wells at least 30-60m. Incorporation is required in both regulations. As well, winter application is prohibited in both regulations. The Washington Act indiscriptly states that application is not allowed if a potential risk of discharge into waters exists, and the guidelines are not much more specific by stating that application cannot take place on bare corn fields between September and February unless the waste is solid or a separated solid. Application is also prohibited on saturated soils and when rain is in the 24-hour forecast. Rates of application are addressed in the Guidelines and are based on soil infiltration rate, therefore they are field specific for every operation and should be based on both soil and manure type. The Guidelines also addressed grassland or pasture management. A pre-harvesting period of 30 days is recommended after land application to allow for die-off of disease-causing bacteria and viruses. This regulation is key to avoiding reintroduction of infection within herds if these crops are used as fodder for livestock.

The liquid application requirements of Iowa's Chapter 65 Rules for Animal Feeding Operations (1999) are shown in Appendix 3.23. Tables 1 and 2 of the Appendix suggest that these MSDs are based on odour and nuisance to the public since the only MSD to differ in Table Two between the low and high pressure irrigation methods is the distance to public use areas. This Act also allows either a 61m MSD to watercourses and wellheads, or, if a 15m vegetated buffer strip is constructed then no MSD is required. Winter application in Iowa is strongly discouraged, but if necessary must only take place on fields with slopes less than or equal to 4%.

Missouri's land application requirements are similar to Iowa's in that MSDs depend on the method of application used and its nuisance potential to the public. For example, if manure is applied through an irrigation system, then a 45.72m MSD is required between the applied field and the public area, but if manure is applied by tank wagon or solid spreader, then only a 15.24m distance is required. Missouri has the largest required MSD between a manured field and a domestic water supply at 91.4m; others include 15.24m from a ditch and 60.96m between applied fields and surface water sources.

Wisconsin's Runoff Management Regulations (2002) do not discuss land application; instead application rates and minimum separation distances are developed for individual operators and recorded in the nutrient management plan. Land application requirements are included in the Guidelines for Applying Manure in Wisconsin (1995). Appendix 3.22 discusses areas suitable for land application, for example, when the ground is frozen, application is permitted at a distance of 91.44m from streams, 304.8m from lakes, on fields with a soil layer of 50cm or more over bedrock, and on fields with slopes less than 6%. These guidelines also address no-till practices by restricting application on land that will not be tilled within 3 days, see Appendix 3.22. Areas where application is never recommended include areas where water flow concentrates and heads toward sensitive areas or floods frequently, and in fields with less than a 25cm soil layer between the surface and bedrock. These guidelines suggest application rates of less than 25 tonnes of manure per acre per year and phosphorous rates of 150lb per acre.

Michigan's Guidelines on the other hand suggest a much smaller phosphorous rate of 42lb per acre. Michigan's Guidelines recommend a MSD of 45.72m between manured fields and surface waters if no practices are used to protect against runoff and erosion. Incorporation of manure is required as soon as possible on lands with slopes greater than 6% and is highly recommended on all fields. Winter application (snow-covered or frozen soil) is to be avoided, but if it is deemed necessary, then manure can only be applied on land with slopes of 6% or less and slurry must only be applied on slopes of 3% or less. Winter application can also only occur on fields that have made provisions for soil erosion, for example, constructed vegetated buffer strips along the boundaries. Michigan's Guidelines address the utilization of stored runoff water, unlike any other jurisdiction reviewed. If runoff water is applied, then soils must be able to accept the water, and the crops must be able to use the nutrients, this application should be saved until there is a dry period when the water could be beneficial.

Minnesota's Feedlot Rules (2000) and regulations are substantially based around 'specially protected areas'. A specially protected area is defined as any land that is within 91.44m of a protected waterbody that has been identified by the state. For example, separation distances to surface waters of 7.6m are required, but if the waters are protected the required distance increases to 30.48m. Similarly, incorporation is only required on protected land or sloping lands, and winter application is only prohibited in protected areas. Application rates in Minnesota are based on phosphorous levels in the soil, and must be such that levels will not increase over a 6-year period. Method of application is also more restrictive in protected areas; traveling guns, center pivots and other equipment that can distribute manure more that 15.24m is prohibited, but can be used elsewhere.

Nebraska's regulations and Acts are similar to Washington's in that Nebraska's Title 130 Rules and Regulations (1972) are utilized in order to comply with the Livestock Waste Management Act (1998). Land application of manure is prohibited within 9.14m of surface water, additionally, a vegetated buffer must be constructed or manure must be incorporated if it is applied within 30.48m. Application is prohibited in the winter and on any other days other than 'dewatering' days. Dewatering days as defined as days that have both suitable weather and soil conditions for land application, for example, not on days when soil is saturated. Application rates in Nebraska must be based on the crop's agronomic nitrogen rate and phosphorous must be limited at 150ppm. Reduced runoff potential of pathogens and nutrients is required, when manure is applied within 30.48m of surface water, through immediate incorporation or direct injection of waste into soil.

3.1.3.3 Land Application of Manure in Other Countries

Maintenance is the key in the Code of Good Agricultural Practice for the Production of Water in England (1998). Proactive examinations of irrigation devices and water courses are encouraged to reduce the risk of water contamination or catch water contamination in a timely manner. Incorporation of manure is required and must be incorporated horizontally on sloped fields to avoid direct channeling with which waste and water runoff could flow. Injection is restricted in fields with drainage systems and must be disked no deeper than the crop's active root zone to avoid leaching in the soil matrix before the roots can take up the nutrients. Grassed buffers are required around watercourses and ditches, and a minimum separation of 10m is required between these and land applied with manure. Waste must be applied at least 50m away from domestic water supply wells, cannot be spread on soil with less than 30cm between the surface and bedrock, and is severely restricted on sloping land. Application rates must not exceed $25m^3$/ha/yr.

Vegetated buffer strips are required when applying manure to land adjacent to watercourses, wells and drains in the Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters (2000) in Finland. All MSDs must be vegetated to further reduce risk of runoff. These MSDs are consistent with most of the other countries reviewed. 10m from a watercourse is standard; and Finland's MSD to a domestic water supply is based on site characteristics.

Scotland's PEPFAA policy (1997) suggests that all operators create field maps siting the risks and suitability of the land for waste application. High, medium and low risk categories of land are defined and must be mapped, see Appendix 3.24 for definitions. Separation distances between land applied with manure and water courses are the same as the MSDs required for the separation of storage facilities and manured fields. Since storage facilities are required to be impermeable and enclosed, it seems that the MSDs for land application should be greater given that manure is exposed to environmental elements and can travel. This is the same fault with all of the minimum separation distances in all of the policies reviewed. Grassed buffer strips are required around watercourses at a recommended width of 10m to retard runoff from manured fields. Application is prohibited on saturated, snow-covered, frozen and sloping surfaces greater than 15 degrees. Spreading is also prohibited when fields have been pipe or mole drained or sub-soiled over existing drains within the last 12 months. Application rates depend on type of material and method used, see Appendix 3.25. For example, slurry that is injected can be applied at greater rates than slurry that is surface-applied.

The Netherlands Manure and Fertilizer Policy (1999) does not give any restrictions with regards to separation distances between manured fields and sensitive geographical features such as watercourses. These restrictions are likely found in another policy legislated in the Netherlands. It does however, restrict the timing of application. Manure cannot be spread on land when it is frozen or snow-covered, and even if it isn't, manure absolutely cannot be spread between September 1st and February 1st on sandy soils. Application is also prohibited on fields with slopes of 7% or greater. Compared to other jurisdictions, a 7% slope is the most restrictive, other slope restrictions have been around 10%. To avoid ammonia emissions, manure must be injected into the soil.

3.1.3.4 Land Application Conclusions

Within the policies reviewed, land application regulations are inconsistent and vary greatly[21]. Some policies require absolute setback distances, whereas others are based on a formula that takes into account topography, type of waste, and method of application. Many of the policies have also included MSDs that are based on odour potential, not risk of contamination of water sources.

Pathogens are addressed with respect to land application regulations in only one of the policies reviewed. The Manure Management Guidelines for Western Washington (1995) addresses pathogens with respect to grazing management. The guidelines recommend a 30 day pre-harvesting period after land application of wastes to allow for die-off of disease-causing bacteria and viruses. This regulation is used to avoid the reintroduction of infection within herds where fields are used as fodder. It is likely that most of the other policies assume that pathogens are controlled in the same way as nutrients are controlled and need not be addressed separately. A better understanding of their control based on existing scientific studies of the transport and fate of pathogenic organisms in agricultural environments is needed; this is the basis of Chapter 4. Until transport and fate of pathogenic organisms is understood, the

[21] This variation may stem from variation in science and the challenges that policy faces because of it.

effectiveness of these regulations at reducing the risk of pathogen contamination in water sources is unknown.

3.2 Bill 81: The Nutrient Management Act, 2002

Ontario's Bill 81, the Nutrient Management Act, was passed on June 27th, 2002. This new legislation addresses environmental concerns and management of land-applied materials containing nutrients. It provides a management framework for Ontario's agricultural industry as well as other generators of nutrient-containing materials including municipalities' sewage sludge. The framework combines environmental protection guidelines for the management of nutrients with current best management practices.

The need for this legislation was addressed at a consultation session in early 2000 held by the Task Force on Intensive Agricultural Operations in Rural Ontario involving farmers, environmental consultants, municipalities and other stakeholders. Since the Walkerton tragedy in May 2000, this legislation has received increased attention and the province quickly moved to develop and implement the Act. It is now part of the province's Clean Water Strategy that was highly recommended by Justice O'Connor following the Walkerton Inquiry. This legislation is also considered an essential tool in source water protection which is the first barrier in a multiple barrier approach[22] to drinking water protection. In light of new expectations of water protection given the recent events in Walkerton, the question is what in this new legislation addresses pathogen management and does it depart significantly from other nutrient management acts?

The Act focuses on new requirements such as a registry of all applicators and generators of nutrient-containing materials as well as the review and approval of Nutrient Management Plans and Nutrient Management Strategies, similar to the separate plans that are required in Delaware. Nutrient units are the key to the new Act. The Act uses a nutrient unit system, rather than a livestock or animal unit system, to measure the amount of nutrients within the waste. Therefore, operators are classified on the amount of nutrient-containing materials generated. For example, livestock operators will measure the level of nutrients that are excreted by their livestock. Nutrient units are used because this Act is simply not focused

[22] The multiple barrier approach involves a set of protection measures put in place to guard against contamination of drinking water. The barriers in this approach include source water protection, water treatment, properly maintained and operated water treatment facilities, and comprehensive training of water treatment operators.

on nutrients obtained from agricultural operations but also from municipal sewage treatment plants, and food processing plants, therefore livestock or animal units are irrelevant. One nutrient unit (NU) is representative of the amount of nutrient-containing waste that is required to fertilize one acre of cropland.

In Spring 2003, public consultations were held across Ontario allowing stakeholders to voice concerns and questions regarding the new regulations. Both Agriculture Minister Helen Johns and Environment Minister Chris Stockwell were present during the consultations and have made amendments to the regulations based on concerns and suggestions that were raised.

The review of the Nutrient Management Act (2002) is focused on the three common issues: nutrient management plans, storage of manures and land application of manures.

3.2.1 Nutrient Management Plans

This act requires two types of approaches, a nutrient management strategy (NMS) and a nutrient management plan (NMP). Most other jurisdictions, other than Delaware, require only one plan because they are focused solely on wastes from agricultural operations. In the NMA, all generators of nutrient-containing materials, including municipal waste treatment plants, abbatoirs, nurseries and food processing plants, are required to be in compliance with the Act. The NMSs must address the generation and reception of waste containing nutrients. Nutrient management strategies are required of all generators of nutrient-containing materials. They must also include the signed contracts between nutrient importers and exporters, a description of the operation, nutrient analysis of materials, and a list of storage facilities to accommodate the material in an environmentally sound manner, see Appendix 3.26 for a complete list of components required. Nutrient management plans on the other hand are developed to describe how nutrient-containing material will be applied to the land. These plans are based on the components of the nutrients and the characteristics of the fields. These plans must be created by livestock operators who keep their manures, as well as cash-croppers that utilize the waste of other operations that do not have sufficient land-base for the amount of nutrients they generate, those operators who accept and apply sewage sludge, such as orchards or nurseries. NMPs will include calculations of the land-base available for nutrient application, soil test results conducted every 5 years, crop requirements, and allocation of materials across the operation's fields based on the runoff potential of the land, and the proximity to sensitive areas such as watercourses, residences or domestic water supplies, see Appendix 3.26 for full details.

Within both the NMP and NMS, contingency plans must be developed. These plans must detail actions that will be taken if equipment breaks down and causes a spill, storage structures are found to leak, weather conditions hinder planned application times, or there is simply more nutrient material that was accounted for in the plans or strategies.

Both NMPs and NMSs must also be approved by certified personnel that work for the MOE or OMAF, and must be updated at least every 5 years. If the amount of nutrients generated or received increases by more than 20% or the operation expands by more than 30NU, a new NMS must be developed. Similarly, a NMP must be revised before the 5 year deadline if there is an increase of 20% or more in the amount of nutrients utilized, the crop removal of nitrogen decreases by more than 20%, or land available for application decreases by more than 10%. All operations will be subject to inspection programs by provincial officers based on their approved nutrient management plans and/or strategies.

3.2.2 Storage of Nutrients

The NMA contains extensive storage regulations including; capacity requirements, minimum separation distances from sensitive areas, and specific field storage requirements, but only addresses the treatment of manure briefly when discussing field storage, see Appendix 3.25 for details. It should be noted that the flooring of an outdoor housing facility is considered to be a constructed storage facility in the Act. The minimum separation distances for the siting of a constructed manure storage facility are generally consistent with other jurisdictions reviewed. In Canada, MSDs to watercourses range from 30m to 100m, the NMA requires 50m. Fifty meters seems like a distance that was chosen so the province could remain in neutral territory compared to the other provinces, it is a safe distance because it is not the least distance, yet it is far from the 100m that other provinces have required.

Private domestic water supplies that are protected by a 6-ft underground casing can be as close as 15m to a storage facility; those that do not have the casing require a 30m distance. Municipal wells on the other hand must be at least 100m away. Most other jurisdictions in Canada do not distinguish between the types of wells and most commonly require a 100m distance between both type and a storage facility, although Minnesota, Texas and Nebraska have developed their regulations in this manner as well.

The capacity of manure storage that is required is one of the highest in the country, behind Alberta and British Columbia, at 240 days. Less capacity will be approved by an officer if it can be shown that the combined capacity of an operator and his/her manure broker equals 240 days.

Like the Finland Decree, field storage is extensively covered in the NMA and it is here that composting is addressed. Firstly, waste can only be stored in-field if it is located on a slope of 3° or less, not in a flood plain area, and has a water content of less than 70%. Piles can remain untreated and uncovered for 60 days, or 120 days if the pile is composted or covered. Field stores must be located at further distances from sensitive areas than constructed storage facilities, which is reasonable considering that field piles are exposed to the elements and have a greater chance of leaching or being transported in rainfall into nearby waters. Operators must be aware of their soil classifications and keep field piles off of soils that have a high infiltration rate to further reduce the risk of pollution through leaching.

Similar to other jurisdictions within in Canada, treatment is not adequately addressed. Treatment methods, other than composting, should be addressed in the legislation, especially in a country where composting is only adequate for less than half of the year due to winter temperatures.

3.2.3 Land Application of Manure in the NMA

With respect to land application of materials containing nutrients in the NMA, non-agricultural materials such as sewage sludge, and liquid agricultural materials are treated as riskier materials than solid manure. This can be seen in many of the minimum separation distances presented in the Act. For example, with respect to municipal wells, liquid agricultural materials cannot be spread within the 2-year time of travel zone unless the land has been tilled within the last 7 days and the rate of application is less than $40m^3$/ha. Non-agricultural materials cannot be spread within the 2-year time of travel zone under any circumstances, whereas solid agricultural manure must only remain at least 100m from the well. Municipal well restrictions are greater than private well restrictions because of the risk of exposing a greater number of people if contamination were to occur in the municipal wells. Land application separation distances to private wells are the same as those for constructed storage facilities; 15m for wells with water-tight casing that extends 6 feet below ground and 30m for those that do not, and non-agricultural materials must be spread at least 90m away from the wellhead if it does not have a casing.

In the case where agricultural operators do not have to complete a NMP, land application of non-agricultural wastes and liquid agricultural wastes in fields adjacent to surface waters must be at least 20m from the top of the bank of the water, and solid agricultural material can be applied as close as 10m away. Akin to Texas' CAFO Rules, vegetated buffer zones (VBZ) are required in fields adjacent to watercourses for those operators that must complete a NMP. A VBZ is defined in the Act as a 3m wide strip of continuous vegetated cover measured from the top of the bank of the watercourse. These zones must be constructed prior to the date in which operations must be in total compliance of the plan and Act. Once VBZ are in place, operators cannot spread any materials containing phosphorous or nitrogen within 13m from the top of the bank of the waterbody, unless the materials are injected, incorporated within 24 hours, or applied to land covered with a living crop. These regulations suggest that the runoff potential of a tilled field with a 3m-wide vegetated buffer strip is equal to a non-tilled field with a non-vegetated buffer of 10m. These regulations also address no-till production systems by requiring larger separation distances when no-till systems are practiced.

The filtration of nutrient containing materials through the soil matrix is addressed in the minimum separation distances that are given for both bedrock and groundwater. A minimum of 90cm must separate the surface from the permanent water table, with a minimum of 30cm unsaturated topsoil. The MSD to bedrock is slightly larger at 150cm. This is a strict MSD for non-agricultural materials, but there are exceptions for agricultural materials dependent upon the type of material, if tilling has taken place and the rate of application, see Appendix 3.27 for details. Again, this specific regulation addresses no-till production systems. Because no-till production systems allow easier vertical transport of waste due to undisturbed macropores in the soil matrix, required vertical distances between the surface and bedrock are increased to disrupt infiltration and decrease the risk of groundwater contamination.

Rates of application are important in the Act and are primarily based on site specific characteristics of the fields such as soil hydrologic group, topography, and method of application, see Appendix 3.28. For rates of application, runoff potential must first be determined based on the soil and the slope of the land. Once runoff potential has been determined, various application rates are given, dependent on whether the materials are surface applied, injected, incorporated or applied on land that had been pre-tilled. Incorporation is not necessarily required unless the land is within 450m of a residence, residential area, health or educational facility. If the land is greater than 450m from these structures, the material is only required to be incorporated if it has an odour rating of 03, see Appendix 3.29 for odour ratings. Incorporation requirements are based on the land's proximity to these areas and how odourous the material is. No application is permitted within 25m of a single residence and 50m of a residential area, health or educational facility. If the land where materials are being applied is between 25-90m of a single dwelling and 50-450m of the other designated areas, incorporation is required for materials rated 02 and 03, and highly recommended for 01 material. Incorporation is not required in fields adjacent to watercourses but if wastes are incorporated the area of land that can be applied is greater because the separation distances are cut back.

Winter application is not necessarily prohibited but is severely restricted. No nutrients can be applied to land that is snow-covered or frozen at any time of the year. 'Winter' is defined as the period between December 1st of one year and March 31st of the following year, during this time restrictions apply. Non-agricultural and liquid agricultural materials cannot be applied to fields with slopes greater than 3%, the same applies to solid manure on slopes greater than 6%. Because of the higher risk of runoff during the colder months, application is prohibited on lands that are subject to flooding and ponding, and areas where direct flow leads to surface waters. If the weather conditions during this time allow for the application of materials, then, the materials must be injected, incorporated within 6 hours, or surface-applied only on land that is covered by a living crop. Application rates must also be halved during this time, or separation distances to surface waters must be expanded to 20m.

Application to land that has been tile drained is only restricted for non-agricultural materials and liquid agricultural materials. Tile drains must be monitored during application of these materials unless the field has been tilled within the last 7 days or the rate of application is less than 40m^3/ha. Again, this shows that non-agricultural and liquid agricultural materials are considered riskier materials than solid manure. This is also shown in sections 6.14 and 6.15 of the Act, focusing on pre-harvest and pre-grazing waiting periods after land-application. These periods are prescribed for non-agricultural material only. Similar to Washington's regulation, these waiting periods should also be required for areas applied with agricultural wastes, as it has been shown that manure from livestock operations also contains a number of disease-causing pathogens that survive on surfaces, in the subsurface and in runoff, see Chapter 4. These regulations do not address the issue of pathogens in agricultural waste, and assumes that they do not pose the same microbiological risks as non-agricultural wastes. This fault or omission within the Act strongly suggests that it will not successfully substitute as a pathogen management program. Again, with respect to land application of wastes, the regulation that was specifically created for the control of nutrients may or may not be effective at controlling pathogens; existing studies on the transport and fate of pathogens will help to determine the Act's effectiveness.

3.3 Comprehensiveness of Policies

All water sources are better protected when policies such as those reviewed are put in place, but the comprehensiveness of policies will ensure better protection. Comprehensiveness is defined as including much or all; this can be interpreted as the inclusion of all the various operations that take place within a farming operation, the inclusion of all the types of farming operations that are subject to the policies and the inclusion of all types of nutrients and contaminants that can cause contamination.

If the protection of water quality is the primary goal, all contaminants need to be addressed, including both phosphorous, nitrogen and the abundant microbial contaminants that are contained within these wastes. Most policies that were reviewed focused specifically on one contaminant, namely nitrogen because of its effects on human health as well as the environment, and rarely addressed the existence of microbial organisms. The prevalence, abundance and persistence of these pathogenic microorganisms within wastes alone should be enough to implement policies and regulations for their control. This lack of specific pathogen control strategies stems from an assumption that nutrient management policies are proxies for pathogen management policies, and therefore only one contaminant is targeted.

Comprehensiveness is enhanced when all sources of these contaminants are included in the regulations and the precautionary principle is taken. Ontario's NMA encompasses all generators of nutrients including non-agricultural generators of nutrient- containing substances, such as municipal sewage and food processing wastes. This is a large market that is not included in these types of policies in other jurisdictions. Originally, Ontario's NMA had required all types and sizes of agricultural operations to be in compliance of it's regulations within a certain date. However, a statement has just been released from the Ontario government stating that small farms will no longer have to comply with the Act by the previous deadline of 2008 (Ontario Ministry of Agriculture and Food, 2003). Currently, the province is deliberating about whether small farms will have to comply to the regulations, therefore the comprehensiveness of this Act in terms of the inclusion of all operations has been reduced. Similarly, those policies that address only concentrated animal feeding operations allow significant quantities of nutrients to go unmanaged. In most jurisdictions, in terms of numbers, small farming operations far exceed larger operations, if these operations are not included, it is hard to say whether the policies will be effective overall and minimize risk of contamination.

All processes within agricultural operations must be addressed. The focus has been on storage and land application of these nutrients on fields containing crops, while barnyard areas and grazing management have been addressed inadequately. When fields are used as grazing sites, wastes are randomly and sporadically distributed therefore these areas should also be addressed, and the fact that it is not a controlled application is also important. Washington's Regulations require pre-harvesting periods on land that has been applied with agricultural waste to increase the die-off of disease-causing microorganisms. Similarly, Ontario's NMA requires both pre-harvesting and pre-grazing waiting periods: but for non-agricultural wastes only. Unfortunately, one of the biggest limitations of Ontario's new Act is the assumption that agricultural wastes do not pose a microbiological threat, as wastes such as sewage sludge do. The issue of microbial prevalence in agricultural waste is not addressed adequately in any of the policies.

Treatment is also inadequately addressed and is closely related to the issue of microbial contamination. If pathogens and other bacteria were addressed more satisfactorily, the issue of treatment may be addressed also because of the ability of treatment processes to sufficiently kill pathogenic organisms. Some policies include shorter MSDs if manure or wastes have been treated prior to application but the treatment process itself is not discussed.

Erosion and sediment control strategies are critical for decreased contamination of source waters, considering that nutrients and pathogens are adsorbed onto soil particles and can be transported in runoff waters. Wisconsin's 'Tolerable Soil Erosion Rate' prevents practices that will cause unsustainable levels of erosion and runoff based on soil type and tillage practices. Other controls include constructed vegetated buffer strips to retard sediment flow from reaching water sources. Erosion can also be controlled in grazing management, by prohibiting livestock from reaching stream banks and providing man-made drinking water sources instead of streams or rivers. This would also decrease direct deposit into water sources.

Any regulation that is based on site or operation characteristics will be more effective than homogenous regulations, for example rates of application and minimum separation distances all based on topography, hydrology, vegetation cover, waste type and method. No single minimum separation distance will be effective for every situation, those jurisdictions that take the time and energy to develop individual but understandable regulations should experience greater effectiveness. Homogenous MSDs can be ineffective and unfair in two ways; firstly, they can be too simple and be futile for a number of situations that are found on agricultural operations. Secondly, homogenous regulations are not always set at the least stringent distances, because the standard must try to encompass all situations it may be exaggerated. This could lead to a loss of land that cannot be fertilized and put some operators at an unfair disadvantage. Regulations that are based on site characteristics will ensure farm operators that they are utilizing the most of their land while minimizing risk of contamination.

Comprehensiveness of the policies should also include the active participation of all those involved. If governments want to ensure these policies are being complied with, inspection programs should be enforced. Inspection programs will highlight the seriousness of the policy, and will ensure that nutrient management plans are followed and will detect when NMPs are ineffective and require revision. Participation should also include some proactive monitoring on the operator's part. Self-monitoring and reporting allows operators to determine for themselves how their plans are working, as they will have visible indicators of its effectiveness. Monitoring does not always have to be high tech, but can simply be descriptive such as the colouration of water sources on the property; any noticed floating algae mats or a decreased fish supply. More extensive monitoring involving N and P levels or testing for microbial contaminants in water sources or in the shedding of livestock should be included in inspection programs. There is no commitment to this type of involvement within the new Nutrient Management Act (2002).

No jurisdiction's policy needs to be exactly the same as another's in order to be comprehensive and effective. Because of the number of individual considerations that must be taken on each operation and the complicated science behind the regulations, an absolute solution to waste management would be ineffective. Policies must be inclusive and dynamic, and regulators must allow new findings from applied research to be integrated so that policies are always inclusive of the latest knowledge. Denmark's Minister of Agriculture precisely stated that 'It isn't the farmers' fault that the goals for agriculture have not been achieved, but the fault of politicians' (Farmers Weekly, 1991). Politicians, policy makers, and regulators must always be aware of the latest knowledge, technology and emerging issues so that farmers can better prepare themselves and their operations to protect water quality.

Chapter Four: Scientific Knowledge about the Transport and Survival of Pathogens in Agricultural Surface and Subsurface Environments

As shown in Chapter 3, most manure management policies focus on the control of nitrogen and phosphorous in livestock wastes. Pathogens are left as non-targeted contaminants that are assumed to be controlled under the same regulations. An examination of transport and survival of pathogens provides an understanding of their fate in the agricultural environment. This knowledge will then be used to assess the regulations of the Ontario Nutrient Management Act, 2002 and its ability to control pathogens.

The studies reviewed include those that investigate transport and survival of pathogenic organisms in agricultural environments, including livestock waste storages and field conditions. It must be noted that there is a large amount of information on the issue of municipal waste application on farm land and the spread of pathogens, but these studies were not used in this work. The focus was on studies that analyzed microbial survival and transport in livestock manure and slurries.

4.1 Studies focusing on the Survival of Pathogens

The survival of pathogenic organisms is important because it can result in their ability to contaminate water sources if transport occurs. Based on the evidence, microbial survival depends on a number of interrelated factors including temperature and the antagonistic effects of other microorganisms. Several studies have examined how changes in these factors have affected survival in solid manure, slurry, soil and water.

4.1.1 Pathogen Survival in Manure

Studies show that pathogenic organisms have the ability to subsist in solid livestock waste (see Appendix 4.1). For example, Robertson et al. (1992) found *Cryptosporidium parvum* oocysts remain viable in cow manure for over 176 days. 2.8×10^7 oocysts were placed in a semi-permeable container that was buried in a bucket containing 25 litres of cow manure. The bucket was stored in the dark and kept at 4°C. Enumeration after 176 days found 39.6% (1.1×10^7) of the oocysts viable.

Similarly, Jenkins et al. (1997) also studied *C. parvum* survival at 4°C. *C. parvum* oocysts (10^6 oocysts/g) were seeded into calf feces and stored in glass containers in the dark. Dye permeability results showed 14% of oocysts were still viable after 259 days in one container, and 10% of the oocysts remained viable for 410 days in another container.

For bacteria, Maule's study (1997) of *Escherichia coli* showed less extensive survival rates than the protozoa studies. Survival of the bacteria was greatest in vegetated soil cores. Viable numbers in this environment remained high at 10^7/g of soil after 130 days. *E. coli* remained viable in cattle feces for 50 days, and for 27 days in both cattle slurry and water.

Temperature has been shown to affect pathogen survivability in livestock waste. Temperature can be controlled in laboratory environments and has been examined in a number of studies. Wang et al. (1996) studied the survival of *E. coli* O157:H7 and demonstrated that the bacteria could persist for long periods of time at lower temperatures. This study examined survival at 5, 22 and 37°C. At 5°C the organism survived for 63 and 70 days in low and high inoculum levels respectively. Survival was reduced at 22 and 37°C. At 22°C survival was 49 and 56 days for the low and high inoculum levels respectively, and at 37°C survival was 21 days for both levels.

Himathongkham et al. (1999; 2000) conducted a study on the survival of *Salmonella typhimurium* and *E. coli* O157:H7 in both poultry and cow manure. Plastic bags containing either poultry or cow waste were seeded with 10^3-10^4 CFU/g of both *E. coli* and *S. typhimurium* and were incubated at 4, 20 or 37°C. In the cattle manure, T_{90}[23] values were greatest at 20°C, whereas in poultry manure T_{90} values were greatest at 4°C.

Similarly, Fukushima et al. (1999) studied *E. coli* O157:H7 survivability at 5, 15, and 25°C. Survivability was greatest at 15°C in the cattle waste that had been inoculated with 10^5 *E. coli*/g. However, at an inoculation level of 10^3 *E. coli*/g, survivability was the same at each temperature.

Bolton et al. (1999) found that there was no significant difference in the survival of *E. coli* O157 in bovine feces when it was held at a constant temperature of 10°C compared to outdoor temperatures that ranged from -6.5 to 19°C. The waste was inoculated with 1.7×10^8 CFU/g and placed in sealed containers. Die-off rates under either condition were similar; at the end of the 99 day study the number of viable *E. coli* had declined to 1.5×10^3 CFU/g.

[23] T_{90} values represent the time it takes for a log reduction of the initial inoculum level.

The effect of temperature on protozoa survival in feces has also been studied. Olsen et al. (1999) studied both *Cryptosporidium* and *Giardia* survival in calf feces, soil, and water at -4, 4 and 25°C. In the manure experiments, the feces were mixed thoroughly with the protozoa to yield a concentration of 10^5 cysts/g and 10^7 oocysts/g. This study, the only one to examine *Giardia* survival, showed that *Giardia* cysts are much less viable in feces than any of the other organisms examined. Survival was less than one week at -4°C, and one week at both 4 and 25°C. *Cryptosporidium* survival was greater than 12 weeks at -4°C, 8 weeks at 4°C and four weeks at 25°C.

Not only do pathogens survive for substantial periods of time in manure environments, some studies also showed that growth of bacteria occurred. In both Fukushima et al. (1999) and Wang et al. (1996), it was reported that before *E. coli* O157:H7 began to die-off, they increased in number. Growth occurred at 22 and 37°C in the latter study and at all temperatures in Fukushima et al. (1999).

The results of these studies show that storage of manure for extended periods of time will result in increased pathogen die-off. Results also show that temperature could be used during storage of wastes to kill viable organisms and therefore reduce the risk of pathogen contamination during handling of the waste.

4.1.2 Pathogen Survival in Slurry

Combining livestock wastes for easier handling within an agricultural operation is a common practice. Urine, manure, and wastewater collected and stored together is referred to as slurry. The liquid consistency of slurries allows them to be easily pumped to storage and field locations. During slurry storage, pathogenic organisms have been shown to persist (see Appendix 4.2). It must be noted that the data regarding pathogen survival in slurry are limited to bacterial studies conducted in the 1960 and 1970s; therefore, it must be assumed that there has been no change in manure handling techniques.

In cattle slurry, Rankin and Taylor (1969) studied the survival of *S. typhimurium*, *Salmonella dublin*, and *E. coli*. All pathogens were seeded into the slurry at a level of 5.5×10^6 to 8.8×10^6/ml. The inoculated slurry was stored in covered seven gallon tanks and left outdoors from mid-January to mid-April in England. The experiment was conducted for 77 days. At this time, the viable numbers of both *Salmonella* species were 10^2/ml, and *E. coli* were reduced to 10^3/ml.

Burrows and Rankin (1970) also investigated the survival of *E. coli* (10^6/ml) and *S. typhimurium* (10^6/ml) in cattle slurry in England. Slurry from five different farming operations was collected and seeded with the bacteria. One bin containing 9 gallons of slurry from each farm was used for each bacterium studied. The bins were kept indoors between October and February in England. Both *S. typhimurium* and *E. coli* survived up to 63 days. *E. coli* survived up to 77 days in one sample from a farm that had cleaned its slurry tank three times per week. Therefore it was demonstrated that the bacteria survived longest in the bin with the freshest slurry. The authors indicate that this is due to the increased amount of dissolved oxygen that would be available in fresh slurry and its ability to maintain aerobic bacteria. Maule (1997) also investigated the ability of *E. coli* to survive in cattle slurry. He found *E. coli* survived in slurry for 27 days compared to 50 days in solid feces.

The effect of temperature on pathogen survival in slurry is similar to the results from the solid manure studies. Bacterial survival is greater at lower temperatures. For example, Jones (1976) studied *S. dublin* survival in cattle slurry. 400 ml samples of slurry were seeded with 10^6 organisms/ml of *S. dublin* and stored at 5, 10, 20, and 30°C. Survival at both 5 and 10°C was 132 days, whereas at 20 and 30°C, survival was reduced to 57 and 13 days respectively. Himanthongkham et al. (1999; 2000) obtained similar results. A series of experiments were conducted on the survival of *S. typhimurium* and *E. coli* O157:H7 in both poultry and cow slurry at 4, 20, and 37°C. Slurry samples were seeded with 10^3-10^4 CFU/ml of both bacteria and incubated in plastic bags. Bacterial survival was greatest at 4°C in both cattle and poultry slurry. For example, in poultry slurry, T_{90} values for *E. coli* were 156 days at 4°C compared to 6.9 and 1.9 days at 20 and 37°C respectively.

Generally, studies that examined the effects of temperature on pathogen survival in both slurry and solid waste showed that survival is greater at lower temperatures. At higher temperatures, desiccation in the upper layers of the waste occurs more rapidly and explains why survival is longer at lower temperatures. Desiccation also occurs less quickly in slurries due to the proportion of liquid. Based on the results of Himanthongkham (1999; 2000), survival was generally greater in slurry environments than in solid manure.

The results of these studies could be used to create guidelines for holding times and temperatures during storage for either liquid or solid waste. Based on the survival times shown, storage for a minimum length of time could significantly reduce the level of pathogenic organisms applied to land compared to the application of fresh waste.

4.1.3 Pathogen Survival in Soil

In some farm operations, pathogens will survive in stored wastes and there is a risk that these organisms could enter the soil environment following land application. Pathogen survival in soil after waste application becomes one of the controlling factors in determining the number of organisms available for transport to water sources (Reddy et al. 1981).

The survival of pathogens in soil has been studied extensively. A number of factors such as soil type, moisture, temperature, pH and the antagonistic effects of indigenous microorganisms have all been shown to influence survivability. The studies reviewed demonstrate that pathogens can survive for extended periods in a variety of soil environments (see Appendix 4.3).

Mawdsley et al. (1996b) determined protozoan survival in the soil environment. The objective of the study was to examine *C. parvum* transport in slurry following rainfall, but at the same time the study showed that *C. parvum* oocysts survive in soil cores for extended periods of time. The study was conducted on a constructed clay loam soil bed held on a 7.5% slope. 420 cm^3 of cow slurry were inoculated with 5×10^9 *C. parvum* oocysts and applied at a rate of $50m^3/ha$ onto vegetated soil[24]. Rainfall was simulated 24 hours after slurry application. After 70 days the soil was examined to determine the number of oocysts at various depths within the matrix. The majority of viable oocysts were found in the top 6 cm of the soil cores.

For bacteria, Sjogren (1995) showed there was substantial persistence of *E. coli* in a rye-grass pasture. Sjogren (1995) determined that the majority of the *E. coli* (exact numbers were not given) survived for 41 days, but some of the bacteria that had penetrated the soil matrix remained on the pasture for 13 years.

Similarly, Bolton et al. (1999) studied the survival of *E. coli* O157:H7 in cattle manure applied to grassland. The bacteria were enumerated using two methods. The first method involved using a sterile spoon to remove one gram of the manure from the area. The sample

[24] In this experiment, $420cm^3$ applied onto the soil core was proportional to an application rate of $50m^3/ha$.

was diluted with a maximum recovery diluent (MRD), a mixture of sodium chloride and distilled water, and plated on a sorbitol MacConkey agar (SMAC). The plated sample was then incubated for 48 hours at 37°C. The second enumeration method involved the same dilution process, but the sample was plated on a Tryptic Soya Agar (TSA) and incubated for two hours at 37°C. The sample was then covered with SMAC and incubated again at 37°C for 48 hours. The survival rates were similar using both techniques. After 99 days, enumeration using the SMAC method on its own showed that the bacteria had declined from 7.1 x 10^7 CFU/g to 9.1 x 10^2 CFU/g. The SMAC/TSA enumeration method also showed a decline in bacteria from 2.9 x 10^7 CFU/g to 1.04 x 10^3 CFU/g. It was found that after 85 days, 70% of the soil samples contained *E. coli* O157:H7 and by 99 days that had been reduced to 20% of the samples. Overall, the study conducted by Bolton et al. (1999) showed that *E. coli* O157:H7 can persist for considerable periods in the soil environment. Maule (1997) also investigated the ability of *E. coli* O157 to survive in soil. Viable numbers of the bacteria remained at 10^7 organisms/g of soil after 130 days.

An outbreak of *E. coli* infection among campers in Scotland led to a study that produced results very similar to Maule (1997). Ogden et al. (2002) investigated the survival of *E. coli* O157:H7 in pastureland after campers attending a scout camp became sick in May 2000. Investigations into the infection revealed that sheep had grazed on the site a few weeks earlier and, once tested, these sheep were found to be positive for *E. coli* O157:H7. Heavy rainfall during the camp event resulted in localized flooding where mud and fecal material were abundant. It was determined that the route of transmission was likely via hands contaminated with mud. Ogden et al. (2002) then designed a study to determine the survival time of *E. coli* O157:H7 in the pasture. The study determined *E. coli* survived for 105 days on that pasture. The authors noted that the date of shedding of the bacteria by the sheep was not certain and therefore the survival rate could be greater than the conservative calculation of 105 days.

Soil type has been shown to be an important factor in bacteria survivability. Generally, the literature suggests that survival is enhanced in loam and clay soils due to the greater amounts of organic matter that they contain. Fenlon et al. (2000) studied the survivability of *E. coli* O157:H7 in Scotland on sandy, loam and clay loam soils. This study applied tracer bacteria, not livestock waste, to the soils in plastic lined bins to a concentration of 10^6 *E. coli*/g of soil. The bins were exposed to ambient temperatures for six months, beginning in December. Results showed that sandy soil was least conducive to *E. coli* O157:H7 survival. The bacteria in sandy soils could not be detected after 56 days, whereas survival in loam and clay soils was over 175 days.

Similar results were found when Zibilske and Weaver (1978) studied the survival of another bacterium, *S. typhimurium*, in clay and sandy loam soils. *Salmonella* were inoculated into fresh cattle slurry at a level of 1.5×10^4/g and spread onto clay and sandy soils held in glass containers. The effect of temperature was also investigated and the containers were held at 5, 22 or 39°C. Survival was greatest at 5°C, and in the clay loam soil.

Conversely, Tamasi (1980) showed that sandy soils enhanced survivability of microorganisms. In Tamasi (1980) the effects of temperature and soil type on survival and transport of *E. coli* and *Salmonella* were examined. Liquid manure was inoculated at a level of 9×10^5 CFU/ml of *E. coli* and 10^5 *Salmonella* organisms/ml. The manure was then applied at a rate of 57.67 m^3/ha over garden soil and sandy soil that had been packed into 160 cm deep plastic tubes. Survival rates were determined by taking core samples at 10cm depths and identifying the bacteria. Survival was greater in the sandy soil at both 8 and 20°C. At 8°C, *E. coli* survival was 131 days in the sandy soil compared to 108 days in the garden soil. *Salmonella* also survived for 131 days in the sandy soil compared to 91 days in the garden soil at 8°C.

Soil types have varying abilities to retain water. Clay and loam soils have been shown to retain water for longer periods of time compared to sandy soils (Young and Greenfield, 1923). Water content within the soil has been shown to be an important factor in bacterial survival. Ellis and McCalla (1978) stated that clay soils adsorb water more efficiently than sandy soils after rainfall and water protects microorganisms from desiccation. In a study conducted by Crane et al. (1980), it was noted that soil moisture not only contributed to greater survival rates of fecal coliforms but also supported their growth.

Sjogren (1994) investigated the effects of temperature, moisture, and soil pH on the survival of *E. coli* in soil. The study was conducted in pots containing two sandy loam soils. One soil had an average pH of 6.8-8.3 and the other had a lower average pH of 5.5-7.2. The soils were inoculated at a level of 10^{12}-10^{13} CFU/g. The pots were incubated at four temperatures; 5, 10, 20 and 37°C and two moisture levels, at saturation and 15% saturation. In total there were 48 pots inoculated for a period of 48 days. *E. coli* survival was greater in the pots that had been saturated.

Similarly, Tannock and Smith (1971) studied the effects of moisture and desiccation on *Salmonella* survival in soil. 75cm^2 ryegrass-clover plots were contaminated with a *Salmonella* suspension applied at a rate of 10^8 *Salmonella*/25cm^2. Moisture and desiccation were examined by studying plots that were exposed to direct sunlight and others that were not. Overall, when moisture evaporated from the soil due to direct sunlight, survival was reduced compared to survival in the shaded plots.

As demonstrated by Tannock and Smith (1971), soil moisture is also related to temperature as well as soil type. The plots situated in direct sunlight experienced higher temperatures than those that were shaded and remained moist. Temperature has been shown to be an important factor in pathogen survivability. Results are consistent in studies that have examined temperature and suggest that lower temperatures are optimal for pathogen survival.

For protozoa, Olson et al. (1999) studied the survival of *Cryptosporidium* and *Giardia* in autoclaved and unautoclaved soils at temperatures of -4, 4 and 25°C. *C. parvum* were shown to survive longest at the lowest temperature; 70 days in the sterile soil and greater than 84 days in the natural soil. *Giardia,* on the other hand, showed the greatest survival rates at 4°C for 45 days in both soil types compared to less than one week at-4°C.

For bacteria, Gerba and McNabb (1981) suggested that at temperatures at or below 4°C, organisms could survive for months or years. This is in agreement with the results in Maule (1997). Maule (1997) found that *E. coli* O157:H7 was most stable in all media tested at 4°C.

Zibilske and Weaver (1978) studied the survival of *S. typhimurium* in sand and clay soils at 5, 22 and 39°C. Survival was found to be greatest at lower temperatures in the clay soil. However, in the sandy soil survival was greatest at 22°C. Tamasi (1980) also investigated the effects of temperature on the survival of both *Salmonella* and *E. coli*, in garden soil and sand. Survival was always greatest at 8°C compared to 20°C, except in one instance. In the soil column containing *Salmonella* and sandy soil, survival was the same at 8 and 20°C, at 131 days. In the study conducted by Sjogren (1994) *E. coli* survival was consistently longer at the lower temperatures. In all of the 48 individual experiments, *E. coli* survival was greater at 5 and 10°C compared to 20 and 37°C.

The results of Jiang et al. (2001) do not agree with the results of Sjogren (1994). In Jiang et al. (2001) survivability of *E. coli* O157:H7 in autoclaved and unautoclaved soils was tested. In both soils survival was tested at 5, 15, and 21°C. Survival of the bacterium in both types of soil was shown to be longest at 21°C. The authors note that this may be due to the slower processes of indigenous microorganisms at higher temperatures, and that at lower temperatures the competition of these microorganisms affects the survival of *E. coli* O157:H7.

The pH of soil has also been shown to affect bacterial survival in the soil environment. Cuthbert et al. (1950) observed enhanced fecal coliform survivability and growth and attributed it to a receptive neutral pH level in the soil. This observation was echoed by McFeters and Stuart (1972) who suggested a pH of 6.0-7.0 was optimal for survival. Sjogren (1994) also demonstrated that viability of *E. coli* was greater in soils with a neutral pH.

Rates of application, for both slurry and solid manure, are utilized in many manure management policies and regulations to control the amount of nitrogen and phosphorous applied to the land. Rates of application obviously affect the numbers of pathogens that could potentially be applied to land, but studies that have investigated application rate effects on pathogen survival have had conflicting results. Dazzo et al. (1973) observed an inverse relationship between die-off rates of bacteria and the rate of slurry application. *Salmonella* and fecal coliforms had a higher death rate in soils that had previously received zero or 1.27cm of slurry irrigation per week compared to soil samples which had received higher rates of slurry. These results agree with those of Mallman and Litsky (1951) who also concluded that increasing the organic content of soil, by increasing manure application, caused an increase in the survival of coliforms in the soil. Studies conducted by Crane et al. (1980) on the other hand, disagree.

Crane et al. (1980) conducted experiments in laboratory soil columns and applied either 36.5 or 165 metric tons of manure per hectare on bare clay loam and sandy loam soils. The manure application rate did not influence the decline in fecal bacteria within the soil.

Jiang et al. (2001) studied rates of manure application on *E. coli* O157:H7 survival. Rates were determined by mixing one part manure with 10, 25, 50 or 100 parts soil. The study demonstrated that the more intensive application rate, one part manure to ten parts soil, resulted in a greater deactivation of *E. coli* O157:H7 compared to lesser rates.

The antagonistic effects of indigenous microorganisms on the survival of pathogens in soil have been studied. The most common method for studying their effect is to compare pathogen survival in sterile soils that have been autoclaved with natural soils. Some studies suggest that survival is enhanced in autoclaved soils because of the absence of predation and competition from indigenous microorganisms, while other studies have shown that both bacteria and protozoa have persisted in natural soils.

Jiang et al. (2002) mixed soils thoroughly with various amounts of manure and compared these samples to a soil that had been autoclaved. Results showed that the *E. coli* O157:H7 declined more rapidly in the unautoclaved soil columns, likely due to the interactions of the pathogens with indigenous soil microorganisms. Conversely, Sjogren (1994) demonstrated that the soil used in lab microcosms with indigenous bacteria permitted the survival of *E. coli*.

The study conducted by Olson et al. (1999) investigated this issue with respect to protozoa and had mixed results. The study analyzed the survivability of the protozoa in soil at temperatures of -4, 4 and 25°C, in autoclaved and unautoclaved soils. The study showed that autoclaved soil had no effect on the survivability of *Giardia* cysts but *Cryptosporidium* oocysts fared better in the absence of other microorganisms.

Overall, under a variety of conditions, including various temperatures and soil types, pathogens have been shown to persist for long periods of time in soil environments. A review conducted by Winfield and Groisman (2003) suggests that survival of bacteria is enhanced in non-host environments that closely mimic mammalian host environments, such as in dark, moist surroundings. Although some studies have produced contradictory results, some general conclusions can be made. Lower temperatures, for example, support growth better than higher temperatures, as well as a neutral pH level and loamy clay soils. It must also be noted that although survival is greater in these environments, survival also occurs in less optimal conditions, for example, at low temperatures and in sandy soils. Therefore, the persistence of pathogens in a number of environments increases the risk of transport to sensitive areas where contamination can occur.

4.1.4 Pathogen survival in Water

In some situations, pathogens will survive in soil environments after land application of livestock wastes. If survival persists until rainfall occurs, the risk of transport to ground and surface water sources is enhanced by percolation through soil or in runoff events. Once pathogens have reached water sources, their ability to survive increases the risk of drinking water contamination. In rural water supplies, if pathogen survival occurs, the risk of waterborne illness is increased since supplies do not undergo treatment. Risk is also increased in water supplies that have been contaminated with hardy protozoa that are resistant to chlorination treatments. Studies have shown that pathogenic organisms can persist in various types of water sources, (see Appendix 4.4) including groundwater, surface waters and treated municipal water.

A number of studies have examined differences in survival rates of pathogens in natural versus sterile water. In all but one study, results were consistent and found that survival was greater in sterile autoclaved water samples compared to natural water samples.

To determine the survival of bacteria in water, Flint (1987) examined the survival of *E. coli* inoculated at a level of 10^6 cells/ml into 100ml of filtered or natural river water. Water was held at 4, 15, 25, and 37°C. Results of the study were reported in T_{99} [25]values. A two-log reduction in *E. coli* had not been reached in the autoclaved water at the end of the 260 day study at 4 and 25°C. However, in the sterile water at 37°C, *E. coli* was reduced to the T_{99} level in 60 days. Viability in the natural waters was drastically lower than the filtered water and viability decreased as temperatures increased.

Wang and Doyle (1998) also studied the survival of *E. coli* O157:H7. The bacteria were inoculated at a level of 10^3 CFU/ml into various water sources including autoclaved municipal water, reservoir water, and water samples from two recreational lakes. Survival was shown to be greatest in the autoclaved municipal water and least in the lake water. This study determined that *E. coli* were entering a viable but non-culturable state because the organisms could be detected by a direct viable count but could not be detected by enrichment in Typticase Soy Broth (TSB). This dormancy that organisms were entering is a means of protection for survival in harsh environments. The authors suggest that the *E. coli* cold survive in this state for much

[25] T_{99} is the time it takes for a two-log reduction from the initial inoculum level.

longer than the 91-day study period and this shows the ability of *E. coli* to survive in water sources.

The results of Rice and Johnson (2000) agree with the previous studies. Survival of *E. coli* O157:H7 was studied in water for dairy cattle[26]. Two sources of water were studied; water from a well that was then chlorinated and water from a surface source. Two grams of manure were added to the two litre water samples containing approximately 1.7×10^2 *E. coli*/ml. The samples were then stored in the dark for 16 days. At the end of the study, survival was greater in the chlorinated water samples where 1.7 *E. coli*/ml remained compared to less than 0.002 *E. coli*/ml in the surface water sources.

McGee et al. (2002) also studied the survival of *E. coli* O157:H7 in treated and untreated water in a number of settings, including outdoors with and without manure added, in a barn, and in a lab environment held at 15°C. Each experiment used five litres of water placed in a 10L sealed container. The water was then inoculated with either 10^3 or 10^6 *E. coli*/ml. Results showed that *E. coli* fared better in the autoclaved water in most settings and at both inoculation levels.

Winfield and Groisman suggest that *E. coli* has a low rate of survivability outside its animal host, unless it is found in tropical water environments. These tropical waters provide high concentrations of nutrients and have constantly warm water and soil temperatures, thereby providing an optimal environment for survival and even growth. The authors suggest that survival is greatest in these environments due to the similarity to animal host environments. This study also shows that *Salmonella* survival in nonhost environments is greater than *E coli* survival. The study suggests that Salmonella have the ability to infect a number of hosts in their lifetime because they can survive outside of mammalian hosts in water and soil environments, increasing the probability of re-infection (Winfield and Groisman, 2003).

Medema et al. (1997) studied both bacteria and protozoa survival in natural and autoclaved river water samples. Water samples were inoculated with either *E. coli* or *C. parvum* at a level of 10^4 CFU/ml or 10^5 oocysts/ml, respectively. Die-off rates were greater in the natural river water samples than in the filtered samples, for both organisms.

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[26] Although this study examines survival in water for cattle not drinking water, it is still valuable in that it shows substantial survival of *E. coli*.

Robertson et al. (1992) also studied *C. parvum* survival in both treated and untreated water. However, results disagree with the previously discussed studies and show that viability was the same in both river and filtered water samples. In both waters, one percent of the 2.8 x 10^7 oocysts that were inoculated into each sample remained viable after 176 days.

Temperature has also been shown to be an important factor in pathogen survivability in water sources. Overall, studies have concluded that lower temperatures are more optimal for pathogen survival than higher temperatures which is consistent with the survival in manure and soil studies.

For bacteria, Flint (1987) demonstrated that *E. coli* viability decreased as temperature increased from 4 to 37°C. The results from Terzieva and McFeters (1991) agree. *E. coli* survival was shown to be greater at 6°C than at 16°C in irrigation stream-water. At 6°C, the T_{90} value for the bacteria was 2.2 days whereas at 16°C it was only 1.3 days.

Wang and Doyle (1998) also studied the survival of *E. coli* O157:H7 in water held at 8, 15 and 25°C for a period of 91 days. The results demonstrated that survival was greatest at 8°C and least at 25°C. At 8°C *E. coli* was viable for over 91 days in all water samples. Rice and Johnson (2000) also confirmed that *E. coli* O157:H7 persists in water samples and that lower temperatures enhance pathogen survival. Die-off rates of *E. coli* were greater at 15°C compared to 5°C.

Medema et al. (1998) studied both *E. coli* and *Cryptosporidium* survival in water at 5 and 15°C. Results showed that the survivability of both organisms is affected by temperature and that lower temperatures are more optimal for survival. This study also showed that *Cryptosporidium* oocysts are much more persistent in the water environment than *E. coli.*

Protozoa survival in water at different temperatures was investigated by Olson et al. (1998). Survivability of *Cryptosporidium* and *Giardia* in sterile distilled water and -4, 4 and 25°C was examined. *Cryptosporidium* survival was greatest at -4°C, whereas *Giardia* survived longest at 4°C.

Largely, the studies demonstrated that pathogenic organisms are capable of long periods of survival in the water environment. Overall, the rates of survival in manure, slurry, soil and water show that normal conditions in agricultural operations favour survivability. Survivability has been shown to be enhanced at lower temperatures but at all temperature levels it has been shown to occur. Similarly, in the soil environment survival is enhanced in clay and loam soils but can occur in sandy soils as well. Nutrient management land application regulations do not address or include strategies to reduce pathogen survival; therefore if they are to effectively reduce the risk of waterborne contamination they must minimize the potential for pathogen transport.

4.2 Studies focusing on the Transport of Pathogens

The transport of pathogens is important because their ability to travel under various management practices and situations, coupled with their ability to survive in agricultural environments, increases the risk of water contamination and waterborne illness. In order to analyze the ability of the Ontario Nutrient Management Act regulations to control pathogens, an understanding of their ability to be transported and factors that affect their transport is required.

The two primary modes of travel for pathogenic organisms include transport through the soil matrix (vertical) and horizontal transport over land in runoff. Both routes of transport have been taken by pathogens that have been implicated in waterborne disease outbreaks.

4.2.1 Vertical Transport in Soil

Mawdsley et al. (1996b) concluded that unless land is saturated or of an impermeable nature, vertical movement of microorganisms through the soil will occur when wastes are applied. The rate of vertical transport depends on the mechanisms of adsorption and filtration which govern transport of pathogens in the soil matrix. Both adsorption and filtration are influenced by soil type and organic matter, rainfall and soil structure, as can be seen in the studies summarized in Appendix 4.5.

Soil Type

Soils function as protection zones over groundwater aquifers by filtering and adsorbing microorganisms thereby retaining them and reducing vertical transport. The soil's ability to filter out microorganisms depends on its texture and pore space (Ellis and McCalla, 1978; Entry et al. 2000). Clays, for example, have the smallest particle size of any soil type at 0-2μm (Bitton and Gerba, 1984), whereas sand particles range from 50-100μm (Bitton and Gerba, 1984). When particles are smaller, they fit together better, reducing the spaces through which organisms can travel. The porosity[27] of silts and clays is the largest at 50-60%, because there are so many minute spaces between the particles. Although there are a large number of spaces, they are usually too small to allow pathogens through. Bollag and Stotsky (1993) agree and state that the lower porosity (30-50%) of sandy soils allows deeper transport through soil layers.

Clay's ability to retain microorganisms is also attributed to its higher organic matter content. Organic matter allows greater microorganism adsorption because it provides additional surfaces to which microorganisms can attach.

The results of Smith et al. (1985) agree with these arguments. Smith et al. (1985) investigated *E. coli* transport in intact and disturbed soil columns with silt loam and sandy loam soils. A suspension of *E. coli* containing 10^7cells/ml was applied over the soil columns and the columns were irrigated at a rate of 200mm/hr. The study concluded that *E. coli* was transported more efficiently in the intact soil columns but that transport and leaching also occurred in the disturbed soils at a lesser rate. Of the intact soil cores, the sandy loam cores permitted the highest rate of *E. coli* transport to 28cm. However, in all of the soil columns, the amount of *E. coli* contained in the leachate exceeded the Canadian Recreational Water Quality Guidelines of less than 100 organisms/100ml.

The majority of the study findings suggest that the degree of adsorption is greater in clay soils compared to sandy soils. However, some studies suggest that other factors affect transport because they demonstrated greater transport in clay and loam soils. For bacteria, Tamasi (1981) showed that leaching was greatest in silty soils compared to sandy soils. Tamasi (1981) conducted a study examining the effect of soil type on the subsurface transport of *E. coli* and *Salmonella*. The organisms were seeded into liquid manure at a level of 10^5 *Salmonella*/ml and 9×10^5 *E. coli*/ml. The manure was then applied at a rate of 57.67 m^3/ha over the garden and sandy soils that had been packed into 160cm long plastic tubes. Rainfall was simulated and it was shown that transport to 160cm occurred in all of the garden soil tubes but not all of the tubes containing sandy soils.

Ogden et al. (1999) also investigated bacterial transport in contrasting soil types. This study investigated *E. coli* transport in 600m^2 grassland plots in clay loam, silty clay loam and

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[27] Porosity is the total volume of pores, cracks, fissures and solution channels per unit volume of material in its natural condition (Bitton and Gerba, 1984).

sandy loam soils. This investigation also examined various application rates on soils, 40t/ha was applied to the clay loam soils, 50t/ha to the silty clay loam soils and 30t/ha was applied to the sandy loam soils. *E. coli* inoculation levels were also different for all soil types making it difficult to analyze the effect of soil type on transport. However, it was concluded that some soil types hinder the transport of bacteria but, in rainfall events transport can occur regardless of soil type. This was shown in the clay and silty clay loam soils, where rainfall events resulted in transport to lysimeter pans, whereas rainfall did not occur over the sandy loam plot and transport to the lysimeter was less than the other plots.

For protozoa, Mawdsley et al. (1996a) studied the transport of *C. parvum* in intact soil cores to examine pathogen transport in differing soil types. *C. parvum*, at a level of 1×10^8, was applied directly onto 30cm deep soil cores of silt loam, loamy sand, and clay loam. The study showed that transport was greater in the silty loam and clay loam soils compared to the sandy soil.

Rainfall

Bitton et al. (1974) stated that bacterial movement should be insignificant when soils are below field capacity moisture levels and that the risk of transport should increase when rainfall occurs. The contamination that transport due to rainfall can cause was experienced first-hand in Walkerton in May 2000 when higher-than-normal rainfall provided a mechanism for the transport of land-applied pathogen-laden manure. Intense rainfall not only creates runoff but also creates turbulent flow through soil macropores that can dislodge microorganisms that were adsorbed within the soil matrix (Crane and Moore, 1984).

Results of the study conducted by Fenlon et al. (2000) agree and concluded that rainfall aided in transport of *E. coli* to tile drains. In this study, dairy slurry containing 5.3×10^4 *E. coli*/ml was applied at a rate of $19.6 m^3$/ha to a clay loam plot. Natural rainfall occurred between the third and seventh days following application. These rain events permitted 7% of the *E. coli* that had been applied to leach into the tile drains. Although the percentage seems low, 7% of the initial inoculation level equals 3.7×10^3organisms/ml which exceed recreational water quality guidelines. Fenlon et al. (2000) concluded that following application to land, the bacteria had adsorbed to the soil in the subsurface but were then 'flushed' through the matrix as a result of the rainfall.

Both Tamasi (1981) and Abu-Ashour et al. (1998) also concluded that intense rainfalls increased transport of *E. coli* and the greatest transport events took place after heavier rainfalls. Tamasi (1981) also noted that normal agricultural rainfall did not lead to transport to deep soil layers.

Gagliardi and Karns (2000) also simulated rainfall events over intact and disturbed soil columns to determine the transport of fresh manure and *E. coli* O157:H7 in three soil types. Fresh manure inoculated with *E. coli* was spread over disturbed and intact soil cores of silty clay and sandy loams. A rainfall rate of 25.4mm over a 4 hour period was applied daily for 4 days and then every fourth day until the end of the 18 day study. The rainfall events led to moist soils and high levels of bacterial growth resulted. The results showed that the rainfall increased transport and, in all but one soil core, higher levels of *E. coli* were found in the leachate than were initially applied in the manure.

Overall studies have shown that rainfall events increase transport opportunities for pathogens. Many nutrient management policies regulate the timing of waste application onto land based on weather forecasts. However, the fact that organisms can survive for extended periods of time in soil environments allows them to remain viable within the soil matrix until rainfall events occur.

Soil Structure

Many nutrient management policies encourage or require tillage or incorporation of manure directly into the soil in order to remove manure from the soil surface and reduce risk of runoff. Tillage and incorporation also disturb macropores and minimize the risk of rapid transport through the soil matrix. Macropores are large, readily visible continuous openings in field soils (Beven and Germann, 1982). These openings can be continuous for several meters in both vertical and horizontal directions. Macropores are formed in agricultural land by soil fauna, plant roots, cracks and fissures (Beven and Germann, 1982). The soil's ability to retain microorganisms, manure and water is reduced when macropores are present and preferential water flow is strong.

A study conducted by Vervoort et al. (2001) reinforces the importance of macropores in solute movement. The study used a blue-dye to follow infiltration in silt loam plots. After rainfall, maximum percolation depth in the no-till soil was more than double the tilled fields.

The tracer in the no-till fields reached a depth of 364.8mm while the tracer in the tilled field reached 131mm.

A number of studies have also been conducted on the effects of tillage on pathogen transport (see Appendix 4.6). In Smith et al. (1985), the transport of *E. coli* through intact and disturbed soil columns was investigated. Soil structure was related to the transport of the bacteria and *E. coli* moved rapidly through the intact soils. When channels and pores were removed by mixing the soil in the columns, soils became more effective bacterial filters. An *E. coli* suspension containing 10^7cells/ml was applied to the soil columns at a rate of 20mm/hr for 10 hours. Disturbed cores retained at least 93% of the cells applied, whereas the intact cores retained only 21-78% of the bacteria. The transport in the intact soil cores shows that the absorptive and retentive abilities of soil are limited when macropores exist.

Abu-Ashour et al. (1998) also studied the effect of macroporosity on *E. coli* transport in saturated and unsaturated conditions in silt loam and loam soils. Experiments were conducted in the lab where soils were mixed and macropores were created artificially. A 35ml *E. coli* suspension containing 10^6-10^{10}CFU/ml was applied to each soil column. Results showed that greater amounts of the *E. coli* consistently passed through the soil columns where macropores had been created.

The results produced by McMurry et al. (1998) also suggest that tilled soils have a greater ability to retain fecal bacteria. In this study, poultry manure was spread on silt loam soil blocks at a rate of one tonne per hectare and rainfall was simulated at a rate of 7cm per hour for 36 hours. In no-till soils, 2.8×10^6 CFU/100ml were found in the leachate after 8cm of rain. In the tilled soils, 2×10^6 CFU/100ml were found in the leachate only after 22 hours of rainfall had occurred. The authors suggest that contamination of groundwater can occur in only a modest rainfall in soils that are not tilled. It was also demonstrated that although tillage retarded preferential movement, it did not prevent leaching of the bacteria.

Gagliardi and Karns (2000) also noted that tillage retarded but did not prevent transport of bacteria through soil cores. *E. coli* O157:H7 transport was examined in intact and disturbed soil cores of silt, clay, and sandy loam. Cattle manure that had been inoculated with 3.0×10^7CFU/ml was applied at a rate of 6.12t/ha onto the intact soil cores. On disturbed soil cores, manure inoculated with bacteria at 4.7×10^7CFU/ml, was applied at the same rate. Rainfall was simulated at a rate of 25.4mm per day for four days and then every fourth day until the end of the 18 day study. *E. coli* was found in the leachate from both the tilled and no-till cores. Leachate from the intact silt loam cores contained more *E. coli* than from the disturbed cores, however, leachate from the disturbed clay and sand cores contained more *E. coli* than the intact cores. In most leachate, the amount of *E. coli* removed was greater than the initial inoculum level; therefore the authors concluded that growth had also occurred. The increased amount of *E. coli* in the leachate of the disturbed cores may indicate that disruption and slower transport allows for more growth opportunity within the soil matrix.

Stoddard et al. (1998) also studied the effect of tillage on bacterial transport. Dairy manure had been applied at rates between 8.6 and 15.9t/ha on silt loam fields, one that had been tilled and one that had not over the two-year study. Lysimeters were installed in the fields at a depth of 90cm to monitor for fecal bacteria in the leachate. Rain was not simulated but after the first natural rainfall, fecal coliforms were found in the lysimeter pans in both fields. The average amount of indicator organisms in the lysimeter pans of the tilled and no-till fields were not significantly different, and averaged 3×10^3FC/100ml.

The results of the Stoddard et al. (1998) study are similar to those found in the research conducted by Wall et al. (1998). This study also concluded that tillage did not result in a significant difference in the levels of bacteria in tile drain waters. Wall et al. (1998) studied the vertical transport of *E. coli*, inoculated into liquid swine manure (the inoculation level not given). The manure was applied to tile-drained fields under three application methods; surface applied, modified injection, and conventional injection[28]. Overall, results showed no significant difference in the levels of bacteria that reached the tile drains (at depths of 0.87, 0.80, and 0.67m) under any of the three application methods. In every experiment, bacteria levels were significantly greater than the Guidelines for Canadian Recreational Water Quality of 10^2 organisms per 100ml.

4.2.2 Pathogen Transport in Runoff

After land application of livestock wastes, a large amount of organic matter and microorganisms remain on the soil surface and within the top 1cm of the soil (Gerba et al. 1975). This increases the likelihood of contamination during runoff events.

[28] Although this study focuses on application method, it is included in this section because modified injection involves minor cultivation prior to injection of waste. Therefore the effects of tillage are also investigated.

McCoy and Hagedorn (1979) studied both vertical and horizontal transport of tracer strains of *E. coli* in silty clay loam fields on a 14% slope. A 500ml suspension containing 10^6cells/ml of tracer bacteria was injected into the soil at 3 depths that corresponded to the A, B, and C horizons[29] in the soil. Piezometers[30] were situated at various lengths and depths downfield from the application site to measure distance traveled. The deepest point measured was 200cm and the farthest distance measured was 20.5m. Tracer bacteria traveled 20.5m horizontally through the soil and were found as deep as 150cm.

Abu-Ashour and Lee (2000) also investigated transport of tracer strains of *E. coli*. In their study, transport on clay loam at a 2% slope and a 6% slope was investigated. Forty litres of water containing 2 x 10^{12} CFU was spread onto both plots. Two days after application, heavy rainfalls occurred. Results showed that transport was greater on the steeper slope. The bacteria from the 6% slope traveled 35m downslope, at this distance runoff contained 16 CFU/ml. On the gentler slope, bacteria were transported 20m and runoff water at this distance contained 15 CFU/ml.

Protozoan transport in runoff has also been studied. Mawdsley et al. (1996b) investigated horizontal and vertical transport of *C. parvum* on a sloping surface. The objective of the study was to examine to what extent *C. parvum* in slurry are transported following rainfall on a 7.5% slope. *C. parvum* oocysts were mixed into cow slurry and the mixture was applied at a rate of 50m^3/ha. At this rate, 1.7 x 10^9 oocysts per soil block were applied. Rainfall was simulated 24 hours after slurry application. Runoff occurred immediately and oocysts continued to be detected in runoff for 21 days (no levels were given). At the end of the study, the soil blocks were examined to determine oocyst location. At the farthest point from the application site, a distance of 70cm, no oocysts were found in the soil cores. The authors suggest this implies that once oocysts are contained in an aqueous solution, they don't precipitate out and settle onto the soil surface. The authors note that if the study had been

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[29] The A horizon of the soil is the top layer, usually no deeper than 20cm. This layer is the most fertile because of the organic matter than accumulates in it and the biological activity that takes place due to the root density in this layer. The B horizon is the layer directly below the A horizon, known as subsoil. The subsoil is lighter in colour because less organic matter and humus is contained in it. Subsoil is denser than the upper layer and fewer plant roots penetrate into it. The C horizon is the layer below the subsoil called 'parent material'. The C horizon contains material that has been around for a long time, as opposed to the organic matter and humus that accumulates and creates the A horizon. This layer usually contains clay and gravel.

[30] Instruments used to measure pore water pressure in soil or rock.

conducted over a longer distance, runoff would still contain a number of oocysts because of their ability to remain in the aqueous solution.

Tate et al. (2000) also studied the transport of *Cryptosporidium* oocysts in runoff over pasture. The objective of the study was not to demonstrate distance traveled but to determine the strength of runoff flow on slopes of 10, 20 and 30%. 200 gram fecal pats were inoculated with 10^5oocysts/g and placed on each slope. After rainfall, runoff was measured one meter downslope from the fecal pat. Strength of the flow was demonstrated by the number of oocysts that were contained in the runoff from the slopes and it was demonstrated that slope had a significant effect of the number of oocysts contained in the runoff. On the 10% slope, 112 oocysts/l were found in the runoff, whereas on the 20% slope, 2.5×10^3oocysts/l were found. The velocity of runoff on the steeper slope flushed oocysts from the fecal pats.

Vegetated Buffer Zones

The construction of vegetated buffer zones surrounding water sources is a common water quality protection measure that has been adopted or encouraged by a number of nutrient management policies because they are a practical, low-cost means of improving runoff water quality (Edwards et al. 1996).

The primary function of a vegetated buffer zone is to control soil erosion and runoff intensity. Vegetated buffer strips function by promoting filtration of soluble pollutants and the deposition of sediment. This is accomplished by the slowdown of runoff when it enters the buffer and the adsorption of pollutants to surfaces of plants within the buffer. Appendix 4.8 shows the details of studies that have been conducted on the effectiveness of vegetated buffer zones with respect to microorganism control.

Young et al. (1980) evaluated the ability of filter strips to reduce pollutants in runoff from feedlot areas. Although this study investigated feedlot runoff, not runoff from land applied with livestock waste, it is important because it shows that total nitrogen and phosphorous within the runoff were controlled more effectively than fecal and total coliforms. Heavy rainfall events were simulated over a 4% sloping area that ran from inside to outside the feeding area. It was shown that the 27m buffer strip reduced the amount of both total coliforms and fecal coliforms by 69% compared to the reduction of total N and P by 84 and 83% respectively. A reduction of 69% resulted in a level of 2.79×10^7 total coliforms and 2.4×10^6

fecal coliforms remaining in the runoff after it had moved through the buffer strip. The authors suggest that a 36m buffer would be adequate to reduce bacteria in runoff to acceptable levels.

Walker et al. (1990) modeled animal waste management practices and their impacts on bacteria levels in runoff from agricultural lands. One of the practices modeled was the use of vegetated buffer strips. The models calculated bacteria concentrations in runoff that resulted from a rainfall event that occurred after manure application. The overall conclusion was that buffer strips alone were not adequate for reducing bacteria concentrations to levels that would meet water quality standards. The model tested a 30.5m buffer strip on a 3% slope and determined that if 2.2t/ha of manure inoculated with 400 fecal coliforms/g was applied to a silt loam field, the buffer would be inadequate in reducing fecal coliform concentrations to acceptable water quality standards. All water samples from the study were found to contain greater than 10^2 fecal coliforms/100ml.

Both Chaubey et al. (1994) and Coyne et al. (1995) showed that vegetated buffer strips control nutrients and sediments more effectively than fecal bacteria. Chaubey et al. (1994) evaluated the effectiveness of filter strips in retaining swine manure constituents including fecal coliforms and suspended solids. A series of buffer lengths were tested (3, 6,9,15 and 21m) after 200kg of N/ha of manure was applied and rainfall at a rate of 50mm/hr was simulated. Results showed that the effectiveness of the buffer strip in retaining total suspended solids was 61%. Fecal coliform retention was slightly less at 58% and even at the 21m distance a concentration of 15.2×10^4 CFU/100ml of fecal coliforms remained in the runoff. Similarly, Coyne et al. (1995) also investigated soil and fecal coliform retention by filter strips after simulated rain events. Poultry manure mixed with bedding from a laying facility was incorporated into a silt loam field and heavy rainfall was simulated over the application area but not over the buffer strip. The trapping efficiency of a 3m buffer strip was estimated. It was found that a 3m buffer was effective at trapping 99% of sediment loads but only 74% of fecal coliforms. The study does not give the inoculation level of the fecal coliforms; therefore it is uncertain whether trapping 74% of fecal coliforms is adequate to achieve water quality standards. The authors note that rainfall was applied over the buffer strip, therefore their estimates of trapping efficiency may be high because, if water had been applied over the strip, there would have been more water to retain a higher number of fecal coliforms.

Lim et al. (1998) studied the effect of a vegetated buffer on the removal of fecal coliforms after cattle manure was applied to a silt loam field. Manure inoculated at a level of 2 x 10^7 fecal coliforms/100ml was applied at a rate of 60kg N/ha. Lim et al. (1998) determined that fecal coliform concentrations in runoff were reduced to zero after runoff moved through a 6.1m buffer with 100% cover.

A study conducted by Entry et al. (2000) found that vegetated buffers were not adequate at retaining fecal bacteria. In this study swine lagoon wastewater containing both fecal and total coliforms was applied at a rate of 86.7m^3/ha over a series of 30m long riparian filter-strips with differing amounts and types of vegetative cover. The study concluded that despite the presence of vegetation, levels of bacteria in wastewater did not decline significantly as the water moved through the strips. It was determined that fecal and total coliforms were reduced by 2.0-3.0 logs in the 30m buffer. Based on the number of bacteria that were initially applied, these reductions would not be adequate to meet water quality standards (see Appendix 4.8).

For protozoa, Atwill et al. (2002) studied the transport of *Cryptosporidium* oocysts in a fluorescent assay through vegetated buffer strips to determine their filtration efficiency. The objective of the study was to assess the assumption that placing a vegetated buffer strip between farmland and water sources will strain or adsorb microorganisms as they move through the buffer. The study demonstrated that buffers were more effective at removing *C. parvum* when constructed with silty clay or loam soils than with sandy soils. Atwill et al. (2002) concluded that a 3m buffer should remove up to 99% of *C. parvum* oocysts when low to moderate precipitation occurs. It must be noted that Atwill et al. (2002) suggested that if higher degrees of rainfall occurred, a larger vegetated buffer strip would be required.

Largely, these studies demonstrate that pathogens have the ability to be readily transported through vegetated areas. These studies also suggest that inadequate bacterial removal could cause contamination of water sources even though adequate practices for soil erosion and nutrient control are in place because sediments and pathogens are transported differently.

Oocysts, cysts, and *E. coli* bacteria typically have a net-negative surface charge which disallows them to strongly absorb to negatively-charged organic matter and clay minerals. When soils are transported by runoff into vegetated buffers, the ‘clumps’ of soil are disaggregated when they collide with the vegetation of the buffer (Walker et al. 1990). This disaggregating of micro and macroaggregates releases the pathogens from the soil particles because the sorption is weak and the microorganisms are free to continue to travel in an aqueous solution without binding to other particles. This weak sorption, coupled with the fact that the size of these microorganisms allows their further transport, increases their ability to travel through filter strips. The ability to travel through vegetated filters is enhanced by their ability to survive for long periods of time, therefore, although the rate of travel is reduced in the buffer strip pathogens can survive long enough to travel through it.

4.3 Gaps in the Evidence

There are a number of gaps that need to be addressed regarding the ability to use the results of these studies to assess the effectiveness of nutrient management policies on controlling pathogens in agricultural operations.

Overall, there is a lack of research on this topic. There are few studies that have been conducted on pathogen survival and transport in agricultural operations. Most studies that investigate the effects of waste application onto land have focused on nitrogen and phosphorous. The limited information available suggests that there is a gap in the knowledge of this issue. However, in the last few years there has been a renewed interest in pathogen contamination due to a number of waterborne-disease outbreaks that have occurred in the United States and Canada.

In the transport studies that were reviewed, all but one[31] of the experiments were conducted using simulated rainfall if natural rainfall did not occur or was not possible. Transport has been shown to be enhanced during rainfall. However, this leaves a gap in the knowledge regarding the risk of contamination and the ability of pathogens to move through and over soils in the absence of rainfall. Many policies and guidelines recommend application during periods of dry weather and therefore the risk of land application under this situation should also be investigated.

The studies reviewed were conducted between 1974 and 2002.This time frame suggests that the available technologies and methods for pathogen enumeration as well as preparation

[31] The one exception is Wall et al. 1998. The Effects of Livestock Manure Application Methods on Water Quality Focusing on Nitrogen and Bacteria Transport in Soil. Agriculture and Agri-Food Canada. Guelph, ON. http://res2.agr.ca/initiatives/manurenet/en/res_reports.html

methods are likely different. For example, Fenlon et al. (2000) noted that the type of selective agent chosen for isolating pathogens is important because it can be inhibiting to some strains and not to others. Therefore, some estimates of viability could be low if an unsuitable agent was used. If every study had used the same instruments and methods, it is likely that the results of some studies may have been different.

All of these studies were conducted by inoculating manure with a set rate of one of the pathogens in order to control the number in the fecal material and the number that were then applied to the soils. Most of the experiments used a variety of rates of inoculation and therefore the amounts recovered in the leachate and soil samples are difficult to compare. It is also difficult to determine the number of pathogens that will actually be contained in the manure and will be spread on land in an agricultural operation. What can be noted is that all studies suggest that the inoculation amounts used are similar to average shedding rates that have been calculated for variously infected animals.

Most studies that investigated the ability of pathogens to travel either in the subsurface or over land, controlled the distances at which the pathogens were measured. This shows that pathogen transport is possible, but leaves a gap as to the true ability of pathogens to travel, and these distances are unfortunately sometimes determined only after water has been contaminated. For example, no studies have examined long distance pathogen transport, hundreds of meters or more, despite the fact that in many waterborne disease outbreaks pathogens have traveled these distances. In the case of the Walkerton waterborne disease outbreak, the manure that was implicated in the outbreak traveled a few hundred meters from the field where it was applied to the well that it contaminated (O'Connor, 2002).

These studies have investigated one manure handling approach at a time. Under real circumstances, agricultural operators would utilize a series of management practices to handle livestock waste and reduce the risk of contamination. For example, by the time wastes are land-applied, they have been collected, stored and transported. During this series of events, microorganisms may be growing or dying within the waste. An understanding of the risk of water contamination from land application is limited when the entire manure handling process is not taken into consideration. No study has traced the fate of pathogens within waste through a whole agricultural operation. Studies designed to track microorganism survival from the time of shedding to land application and then track transport would be difficult to design and conduct, but would also be very meaningful. In the meantime, research focusing on pathogen transport and survival in one agricultural environment, for example waste in storage or soil, is important in the understanding of pathogen control and the actions necessary to reduce the risk of water contamination of these microorganisms.

4.4 Conclusions

Investigations have shown that pathogens have the ability to survive in environments common in agricultural operations and can be transported significant distances through soil and in runoff. Despite the lack of information or the differences in design of the studies, for example field vs. laboratory studies, the information that these studies has provided helps to understand the extent to which microorganisms can survive and move under these situations.

Pathogen survival in storage and in the soil environment is enhanced at lower temperatures. However, despite the fact that survival is greater at lower temperatures, it has been shown to occur for significant periods of time in environments up to 35°C, temperatures that could be reached in the environment. Similarly, the studies showed that survival is enhanced in clay and loam soils compared to sandy soils. Again, although survival is greater in clay and loam environments, it has been shown to be substantial in sandy soils as well. Many of the studies determined the optimal conditions for pathogen survival; however, pathogens were shown to survive for extended periods of time in conditions that were less than optimal as well. This ability of bacteria and protozoa to survive in nonhost environments shows the microorganisms' ability to adapt to new environments that are not as optimal for survival and proliferation as were their animal host environments.

The mechanisms that affect microorganism transport were shown to be different than nutrient transport after land application of livestock wastes. Pathogens were shown to be transported greater distances than nutrients attached to soil particles.

The ability of pathogens to survive and be transported differently than nutrients and sediments in agricultural environments suggests that an analysis of specific regulations within a nutrient management policy should be conducted. This analysis will examine whether pathogens are controlled effectively under common nutrient management guidelines or whether these policies, that have been assumed to abate pathogens, unsuccessfully manage the risk of water contamination of manure-borne microorganisms.

Chapter Five: Pathogen Control using Nutrient Management Policy: NMA Regulations and Scientific Conclusions

The objective of this research is to determine the pathogen abatement effects of nutrient management policy, in particular the Ontario Nutrient Management Act (2002), by assessing the regulations' ability to control pathogen transport and survival. The assessment is based on existing scientific studies that have been conducted in agricultural environments or for the purposes of mimicking agricultural environments in a laboratory setting, therefore no in-field research has been conducted and analysis is based on the findings available in these studies. By developing an understanding of pathogen abatement effects, an assessment can be made of the degree of protection that is made available by the nutrient management regulations.

The regulations that were specifically analyzed within the Ontario Nutrient Management Act (2002) include those that focus on controlling and preventing the horizontal and vertical transport of waste once applied to land. These regulations include established minimum separation distances between surface waters and wells under a variety of conditions, the use of vegetated buffer zones, and the prevention of preferential flow to groundwater, bedrock and tile drains.

Part of this analysis involves an investigation of the distance traveled by pathogens and their ability to move under various management conditions, such as tilled versus non-tilled soils. Another factor is the concentration of organisms that travel these distances. The initial concentration of organisms is important to determine the quality of the resulting runoff and leachate, given that 100% die-off of the pathogens is not likely. The Guidelines for Canadian Recreational Water Quality (1992) were used as the requirements in this analysis. Standards for recreational water quality were used since the water resulting from tile drains or runoff will obviously not be used as drinking water. Therefore the allowable concentrations of *Escherichia coli* in recreational water are a geometric mean of <100 *E. coli* per 100 millilitres based on a minimum of five samples taken over a period of 30 days (Robertson, 2003). Will Robertson (2003) of Health Canada indicated in conversation that there are no specific measures for *Salmonella* and noted that when water is measured for *E. coli*, *Salmonella* is also implicitly measured due to their relationship[32]. *Cryptosporidium* and *Giardia* are also without specific water quality standards due to the difficulty and cost of their measurement. Detection of *Cryptosporidium* and *Giardia* requires large amounts of water and there is no efficient method for determining whether the oocysts and cysts that are detected are actually viable (Robertson, 2003). For the purposes of this research, the standard of <100 organisms per 100 millilitres of water was used for all pathogens studied; therefore, if levels of pathogens greater than this standard were found in runoff water, leachate water or tile drains, the water was considered to be contaminated. If contamination was found to occur in experiments conducted under permitted conditions based on the regulations, it indicates that pathogens can survive and be transported under the conditions set out in the Nutrient Management Act.

5.1 Vegetated Buffer Zones

Section 1.1 of the Nutrient Management Act, 2002, defines a vegetated buffer zone as an area that,

a) *Has a width of at least 3m, adjacent to surface water, measured from the top of the bank of the surface water nearest the buffer zone; and*
b) *Is maintained under continuous vegetated cover.*

Based on the studies regarding the effectiveness of vegetated buffer zones (shown in Appendix 4.8), a zone with a width of 3 meters would be inadequate to control the movement of pathogenic organisms because high levels of pathogenic organisms were found to be transported up to 30m from their point of application through buffer zone materials. Seven studies were reviewed; of the seven studies, six recommended a vegetated buffer zone width of greater than 3 meters in order to obtain primary contact water quality standards.

The study conducted by Atwill et al. (2002), was the only study that showed the regulations of the Nutrient Management Act to be adequate in controlling *Cryptosporidium parvum*. Atwill et al. (2002) concluded that 99.9% of *Cryptosporidium* oocysts would be captured in a three meter wide buffer if runoff occurred during a low-to-medium sized rainfall event. It should also be noted that although this was the study conclusion, the authors suggested a buffer strip of 3-7 meters in width to account for higher intensity rainfall events.

[32] Studies have shown that generally, water samples containing high concentrations of fecal coliforms will likely also contain *Salmonella*.

The remainder of the studies (Entry et al. 2000; Coyne et al. 1995; Young et al. 1980; Lim et al. 1998; Chaubey et al. 1994 and Walker et al. 1990) generally found that buffer zones in the range from 6.1 meters to 35.44 meters are required to bring runoff water to acceptable primary contact standards for fecal coliforms and *Escherichia coli.*

The study conducted by Entry et al. (2000) is the only one that measured transport of total coliforms and fecal coliforms during a period without rainfall. Despite the dry conditions, the bacteria were able to move 15 meters through the buffer zone when applied in swine lagoon wastewater at a rate of $86.7m^3/ha$. The slope at the site was not excessive but ranged from 1.5-2.0% and therefore this application rate would have been acceptable under the Nutrient Management Act.

Based on the existing evidence, a buffer zone following the specifications under the Nutrient Management Act, will not adequately prevent the transport of pathogenic and indicator organisms in runoff water as it travels through the buffer based on levels of inoculation that are consistent with average shedding rates of infected livestock.

The results shown in Appendix 4.8 also demonstrate that vegetated buffer zones, as they are defined under some of the other policies reviewed, are also likely inadequate for pathogen control. For example, the Prevention of Environmental Pollution from Agricultural Activity Code in Scotland and the Code of Good Agricultural Practice for the Production of Water in England both require vegetated buffer zones with a width of ten meters around surface sources adjacent to agricultural land. However, based on the conclusions about transport shown in five out of the seven studies reviewed, a 10 meter buffer zone would not succeed in meeting primary water contact standards.

5.2 Vertical Transport and the Prevention of Preferential Flows

There are three sections of the Nutrient Management Act (2002) regulations that are intended to reduce the risk preferential flow and vertical transport of wastes through the subsurface soil environment, including Section 6.4 that deals with tile drainage, Section 6.11 which deals with minimum depth to bedrock, and Section 6.12 dealing with minimum depth to groundwater.

Section 6.4 of the Nutrient Management Act, 2002, Prevention of Preferential Flows to Tile Drains states:

If it is not possible to monitor the tile drainage system, no person shall apply a liquid prescribed material or non-agricultural source material to the land unless,

a) The land has been tilled within the period of 7 days before application; or

b) The rate of application is less than $40m^3$/ha.

It is assumed tillage produces reductions in pathogen concentrations in leachate. This regulation relies on the disturbance of macropores, rate of application, and the filtration properties of soil to prevent vertical pathogen transport. To analyze the effect of this regulation, studies should have applied liquid prescribed materials at rates less than 40 cubic meters per hectare or have tilled the cropland within seven days prior to application. Based on these requirements, not all studies summarized in Appendices 4.5 and 4.6 can be utilized. For example, Mawdsley et al. (1996b) cannot be used in the analysis of these regulations because the study was conducted on intact soil cores and the application rate of cattle slurry exceeded $40m^3$/ha.

It must be noted that depths of tile drains differ in various agricultural operations based on soil, topography, and hydrology of the land. In Ontario, the minimum permitted depth of soil over tile drains is 600mm but can be as little as 500mm under certain circumstances; the average depth of tile drains in Ontario is roughly 750mm (Ontario Ministry of Agriculture, Food and Rural Affairs, 1997). Generally, tiles drains are constructed at shallower depths in clay soils and deeper in lighter soils.

Of the studies that are relevant in this regulation, there are conflicting conclusions regarding the effects of tillage and rates of application on vertical transport of pathogens to tile drains. Patni et al. (1984) showed that transport to depths of 80cm by fecal bacteria is possible, but the concentration of fecal bacteria in the tile drainage water was below the maximum acceptable concentration (MAC), based on primary water contact standards. However, the concentration levels in the tile waters did reach unacceptable levels and were not continuously below the MAC. At times, levels reached as high as 2.8×10^4 organisms per milliliter, but based on the geometric mean of all samples taken, this study showed that the filtration properties of soil, combined with a $40m^3$/ha application rate or tillage of the field to prevent preferential flows, is adequate at controlling the transport of bacteria.

Conversely, vertical transport of bacteria was shown to be significant in Fenlon et al. (2000), Ogden et al. (2001), McMurry et al. (1998), Wall et al. (1998), Stoddard et al. (1998)

and Patterson et al. (1974). The concentration of organisms found in the leachate water or tile drain water in these studies exceeded the MAC despite controlled rates of application for liquid prescribed materials below $40m^3/ha$ and/or tillage prior to application. For example, Wall et al. (1998) studied transport to tile drains on three sites at depths of 0.87m, 0.80m, and 0.67m and found concentrations of *E. coli* at 1.33×10^6/100ml, 5.0×10^3/100ml, and 1.22×10^5/100ml respectively, and Patterson et al. (1974) found similar concentrations of 3.6×10^5/100ml at a depth of 1.5m. Stoddard et al. (1998) investigated the transport of fecal coliforms (FC) in tilled and no-tilled fields. The researchers found no significant difference in the FC concentrations in lysimeter pans at a depth of 90cm where concentrations averaged 3×10^3 FC/100ml.

The study conducted by Tamasi (1981) also follows the requirements of these regulations and shows transport to a depth of 1.6 meters for both *E. coli* and *Salmonella.* However, levels of concentration at this depth are not given, therefore, it cannot be said whether this study shows regulations would be adequate at controlling pathogen transport. Studies conducted by McCoy and Hagedorn (1979) and Rothmaier et al. (1997) show significant transport of *E. coli* at concentrations exceeding the MAC to depths of 150cm and 50cm respectively. These studies were conducted using an *E. coli* suspension instead of livestock slurry or manure, therefore the effects of organic matter in manure are not accounted for and rates of application of manure do not exist. Nonetheless, these studies are valuable because they show that bacterial transport was substantial.

Based on the existing evidence, it can't be stated with certainty whether the requirements of Section 6.4 are adequate to inhibit pathogens from reaching tile drains, but the majority (all but one) of the studies that were conducted under NMA specifications (Section 6.4) do show that bacterial levels are exceeded under the circumstances specified. As well, other studies show significant vertical transport to depths at which tile drains could be located; these studies, however, were not discussed specifically in this section because they did not comply with the requirements of Section 6.4; for example, either the application rates were too high, fields were not tilled, or whether the fields were tilled is not given.

Section 6.11 Minimum Depth to Bedrock

Section 6.11(2) of the NMA, 2002, states that no one can apply agricultural materials if the depth of the soil over bedrock is less than 150cm. If that is the case, operators must follow the application specifications set out in Table 4.

Table 4: Land Application Requirements if distance between surface and bedrock is less than 1.5 meters.

Depth of Soil over Bedrock	**Treated liquid materials, or runoff liquid materials other than untreated liquid manure**	**Solid manure**	**Untreated liquid manure**
Less than 15cm	No application allowed	No application allowed	No application allowed
15 to 30cm	Application allowed under the following conditions: 1) Land tilled within 7 days before application. 2) Maximum application rate less than 40m^3/ha.	Application allowed under the following condition: 1) Maximum application rate less than 45 t/ha.	No application allowed
30 to 60cm	Either, a) maximum application rate less than 40m^3/ha, or b) if land tilled within 7 days before application, max. application rate less than 75m^3/ha.	Maximum application rate less than 85t/ha.	Application allowed under the following conditions: 1) Land tilled within 7 days before application. 2) Maximum application rate less than 40m^3/ha.
60 to 150 cm	No restrictions on application unless imposed otherwise by this Regulation, including any restriction in an applicable nutrient management plan.	No restrictions on application unless imposed otherwise by this Regulation, including any restriction in an applicable nutrient management plan.	Either, c) maximum application rate less than 40m^3/ha, or d) if land tilled within 7 days before application, max. application rate less than 75m^3/ha.

(Adapted from, Ontario Ministry of Agriculture and Food. 2002. Nutrient Management Act, 2002. Legislative Assembly of Ontario.)

The regulations in this section are based on the depth of the soil over bedrock and the type of waste being applied. Again the two mechanisms used to control transport are tillage and rate of application. To analyze the potential outcomes of this regulation, studies had to conform to the specifications laid out in Table 5.1. Of the studies reviewed, four studies were conducted within the specifications. Based on the evidence, all four studies show that the regulations would be inadequate in controlling pathogens in the subsurface soil environment (see Appendices 4.5 and 4.6).

Patterson et al. (1974), McMurry et al. (1998), Stoddard et al. (1998) and Wall et al. (1998) demonstrated that the tillage and rate of application requirements in Section 6.11 of the Nutrient Management Act, 2002, may be inadequate at controlling pathogen transport. Firstly, Patterson et al (1974) applied slurry at a rate of $46m^3$/ha on a ploughed field; this is permitted when depth of soil over bedrock is at least 60cm to 1.5m. Under this circumstance, they found bacterial transport to 1.5m and water with concentrations of 3.6×10^5/100ml fecal coliforms at that depth, therefore water within the bedrock zone could have become contaminated. McMurry et al. (1998) also within the Act's requirements, applied solid poultry manure at a rate of 10 tonnes per hectare over both tilled and no-till fields. When applying solid manure under Section 6.11, there is a maximum of 45t/ha permitted at a depth of soil over bedrock of 15-30cm. They showed vertical transport of fecal bacteria to 42.5cm with concentrations of 2.3×10^7/100ml in the no-till fields. The tilled fields retained the bacteria for a longer period of time but did not prevent it from traveling vertically. After 22 hours, the leachate in the tilled field reached a bacterial level of 2.0×10^7 CFU/100ml. Similarly, Stoddard et al. (1998) investigated fecal bacteria transport in tilled and no-till soils, and found no significant difference in the average concentrations at 90cm deep in either field. In both the tilled and no-tilled fields, average concentrations reached 3×10^3 FC/100ml. Lastly, Wall et al. (1998) also showed that transport of greater than acceptable levels of *E. coli* reached depths of 0.87, 0.80, and 0.67cm under the conditions deemed acceptable in Section 6.11. They applied liquid swine manure at a rate of $66.1m^3$/ha and tilled prior to injection (modified injection); this would allow application on land if depth of soil over bedrock was 60cm to 1.5m. Transport of *E. coli* in this study exceeded acceptable levels in three soil types and all three depths investigated, therefore showing that under normal agricultural practices specified in Section 6.11, pathogen transport is possible.

The other studies in Appendices 4.5 and 4.6 cannot be used to specifically analyze this regulation because one or more of the required conditions are not met in the study; for example, some used an *E. coli* suspension rather than livestock waste; in others, application rates were too high or tillage did not occur on the study site. For example, Tamasi (1981) showed transport of *E. coli* and *Salmonella* to a depth of 160 centimetres in tilled soil at a rate of $56.67m^3$/ha but levels of the pathogens at that depth were not given[33]. This application rate would be allowed if depth of soil over bedrock is 60-150cm, therefore the *E. coli* and *Salmonella* in this study would have reached water within bedrock, but at what level is uncertain.

The evidence of the studies that were conducted within the specifications of Section 6.11 show that this regulation based on tillage and rates of application would likely be ineffective at controlling the transport of pathogens to bedrock under normal agricultural conditions.

Section 6.12 of the Nutrient Management Act, Minimum Depth to Groundwater:

Section 6.12 states that agricultural operators are not permitted to apply prescribed materials to land unless there are at least 90 centimeters of soil over a permanent water table, and that the first 30 centimeters at the surface of the ground must be unsaturated. This regulation relies on the filtration and adsorption properties of soils to retain waste within the top 90 centimeters of soil. Unsaturated soils allow microorganisms to get closer to soil particles because water does not flow through macropores, it flows only through micropores, and this allows easier adsorption to soils (Bitton and Gerba, 1984). Therefore, the regulation specifies application during unsaturated conditions. McCoy and Hagedorn (1979) also conducted a study of subsurface transport under saturated conditions and stressed the need for a large zone of unsaturated soil to prevent the mobilization of pathogen populations in the soil matrix.

Unfortunately, of the studies that have investigated vertical transport of pathogens, most simulate average rainfalls to promote the transport of pathogens through the soil matrix. The study conducted by Wall et al. (1998) is the only one that has investigated the transport of *E. coli* prior to rainfall and immediately following application; this lack of additional evidence under similar conditions suggests that there is a gap in the understanding of this issue. Wall et al. (1998) investigated the transport of *E. coli* in three soil types, but for the purposes of this discussion, the experiment on the silt loam soil will be disregarded because the tile drains were flowing at the time of waste application. They found that despite the dry conditions, transport

[33] Tamasi (1981) repacked soil in soil columns, simulating tillage and disruption of macropores.

in the sandy loam and silty clay soils was significant and bacterial concentrations in the tile waters exceeded acceptable primary water contact levels. Concentrations in the sandy loam soils, at a depth of 80cm, ranged from 5.0 x 10^3 to 6.5 x 10^4/100ml, and concentrations in the silty clay loam at a depth of 67cm ranged from 2.5 x 10^4 to 1.22 x 10^5/100ml. Although these depths do not reach 90 centimeters as specified in Section 6.12, and since the depths measured in the study were controlled by the tile drains, the numbers of organisms per 100ml at these depths suggest that if pathogens were able to continue to move vertically through the soil matrix to 90cm, rates would have remained above the MAC.

It is important to note that other studies show transport to 90cm is possible (Patterson et al. 1974; McCoy and Hagedorn, 1979; Tamasi, 1981; Stoddard et al. 1998; and Rothmaier et al. 1998) under natural conditions and conditions of simulated rainfall (see Appendices 4.5 and 4.6). In both Stoddard et al. (1998) and Rothmaier et al. (1998), experiments were conducted in-field under natural conditions and in both cases waste was applied during dry conditions but leachate was not monitored until rainfall occurred. Unfortunately, there were no measurements taken immediately following application but these studies indicate that the *E. coli* and fecal coliforms were able to survive in the unsaturated soil matrices until rainfall occurred which mobilized retained organisms. The ability of pathogenic organisms to survive in soil for extended periods of time increases their probability of transport because they can remain viable until rainfall events occur.

Based on a single study (Wall et al. 1998) in unsaturated conditions, it is unlikely that the specifications in Section 6.12 regarding water transport to groundwater sources would adequately prevent pathogens from reaching the water table. The evidence from other studies also shows that pathogenic organisms are persistent in agricultural soils and this persistence gives them the ability to remain viable until rainfall and then be transported. Therefore the regulations' ability to retain pathogenic organisms within the soil matrix is severely limited by the ability of bacteria to remain viable for extended lengths of time.

5.3 Horizontal Transport and Prevention of Runoff

The Nutrient Management Act (2002) includes three sections to prevent horizontal transport of wastes in the subsurface environment and primarily through runoff. These include Section 6.6 Setbacks from Wells, Section 6.9 Application Setbacks with Vegetated Buffer Zones, and Section 6.10 Application Setbacks when no Vegetated Buffer Zone exists.

Section 6.6 states that agricultural source materials must not be applied to land closer than:

a) *15m from a well with a water-tight casing reaching 6ft. underground;*

b) *30m from a well with no water-tight casing;*

c) *100m from a well that supplies water to a municipal water works*

These regulations assume that the wells are managed accordingly and are known about, properly maintained, commissioned, constructed and sited. Further, Section 6.9 requires a minimum separation distance to surface waters of 13m from the top of the bank when a vegetated buffer zone exists or, application is allowed within 13m if the waste is injected, incorporated within 24 hours, or applied to a land covered with a living crop. Lastly, if a vegetated buffer zone has not yet been constructed, Section 6.10 states that the minimum separation distance to surface waters from application be 20 meters for non-agricultural and liquid wastes, and 10 meters for solid agricultural waste.

In the review of existing information, few studies measured horizontal pathogen transport either through runoff or in the subsurface. Most focused on the quality of runoff and not distance transported. No studies tested the range of minimum separation distances (MSD) that have been regulated in various jurisdictions across Canada, the United States and other countries to determine which MSDs are effective and which are not. Most investigations of runoff water quality focus on the nutrient quality of the water since nutrients have been a topic of interest in the last decade with the increasing rate of eutrophication in various watersheds across the province and country.

Although the specifications in Section 6.10 regulate the use of liquid agricultural waste more strictly than solid wastes, studies have not been conducted that investigate the difference in transport between the two types of waste, all other factors remaining the same.

Again, the predominant factor in the transport of microorganisms through runoff has been shown to be rainfall, and applications cannot be regulated with certainty since weather systems can change so quickly and forecasting is less than perfect.

The lack of studies investigating this issue suggests a gap in the knowledge regarding the horizontal transport of pathogens on agricultural land. It must also be noted that similar to the vertical transport studies, investigations of the transport potential of pathogenic organisms have been conducted under simulated rainfall or natural rainfall conditions, therefore leaving a gap in the knowledge of transport under dry conditions.

Two studies have reported the horizontal distance traveled by *Escherichia coli* and its concentration levels in runoff water; McCoy and Hagedorn (1979 and Abu-Ashour and Lee (2000) (see Appendix 4.7). Although the evidence is sparse, based on their conclusions, *E. coli* transport in runoff or the subsurface has been shown to be substantial in agricultural soils and able to travel farther than distances established in the Nutrient Management Act in Sections 6.6, 6.9, and 6.10.

The study by McCoy and Hagedorn (1979) that involved injecting an *E. coli* tracer into silty clay loam in a field with a slope of 14% resulted in concentrations of *E. coli* greater than 10^5/100ml found at a 20.5m distance from the injection site. Under the Nutrient Management Act, application on clay soils, considered 'slow' based on the runoff potential of soil hydrologic groups, is prohibited on a 14% slope within 150 meters of a watercourse. However, this study did not apply liquid prescribed materials but injected a biotracer at a depth of 30cm. Although the degree of slope is too large for liquid prescribed materials, solid materials can be applied on a slope of this degree and therefore could travel this distance. If this was the case, the distance traveled would show that the MSDs that have been specified in the NMA may be inadequate at minimizing bacterial transport to nearby surface waters or wells. Since the study was conducted using a biotracer, it can't be said with certainty whether the regulations would control pathogen transport. However, because the *E. coli* were injected rather than surface-applied, it strengthens the argument that pathogens have the ability to be transported.

Abu-Ashour and Lee (2000) conducted an experiment also using an acid-resistant *E. coli* biotracer. *E. coli* transport was investigated on two fields with slopes of 2% and 6%, both of clay loam. Rainfall occurred two days after application and transport was measured; on the 2% sloped field concentrations of 1500 CFU/100ml were found at 20 meters from the application site and on the greater slope concentrations of 1600 CFU/100ml were found 35 meters from the site of application. Although application was conducted on a dry field, the *E. coli* were not measured until rainfall occurred, therefore it is uncertain how much of the *E. coli* was transported prior to the rainfall, but it does show that the *E. coli* survived in the dry soil matrix until rainfall occurred. Although this study was conducted with a biotracer rather than livestock waste, the distances traveled extend past the minimum separation distances set for either slurry or solid waste for application adjacent to surface water sources. Based on these distances, *E. coli* would have also reached wells with water-tight casings or, in the case of the 6% sloped field, would have reached wells without watertight casings 30 meters away at levels exceeding the MAC by 16 times.

Despite the lack of studies on horizontal transport, the results show that a setback distance in the range of 13 meters to 30 meters may not be adequate to prevent contamination of surface waters and well waters under certain environmental conditions. The results of McCoy and Hagedorn (1979) showed a significant distance traveled, despite the injection of *E. coli*. This evidence, coupled with the fact that vegetated buffer zones are inadequate at controlling pathogens, strengthens the argument that the MSD of less than 13 meters[34] may be too narrow to retain pathogenic organisms and prevent surface water or well contamination.

5.4 Pre-grazing and Pre-harvesting Periods

Under sections 6.14 and 6.15 of the Nutrient Management Act (2002), pre-harvesting and pre-grazing periods are required when land is applied with non-agricultural source material; this is an appropriate regulation based on the survival of pathogenic organisms that can be contained in these wastes. However, there is a gap in the NMA (2002) in that there are no required waiting periods after the application of agricultural livestock wastes before grazing and harvesting. This omission suggests that there is no microbiological risk when applying livestock wastes to agricultural lands. The evidence that pathogens are numerable, can persist in soil and pasture environments (see Appendix 4.3), and have the ability to grow in optimal environments, speaks to the need for pre-harvesting and pre-grazing periods after the application of livestock wastes. Studies conducted by Fenlon et al. (2000) and Ogden et al. (2001) support this argument and both suggest that recommended pre-harvesting and pre-grazing periods are necessary to enhance die-off and the ability to control the spread of pathogens. Pre-grazing periods are essential to minimize the risk of the re-infection of herds from consuming pathogens that have remained viable in grazing fields. Herd health is an important factor in controlling the spread of pathogenic organisms throughout agricultural environments. Minimizing infection and re-infection of herds will therefore minimize the amount of pathogens being applied to land. However, herd health and hygiene have little to do

[34] A minimum separation distance of 13m is permitted when a vegetated buffer zone is constructed or when solid livestock manure is applied.

with the control of nutrients and therefore this may be a gap in water protection when trying to control pathogens under nutrient management policies.

5.5 Gaps When Using Nutrient Management to Control Pathogens

Pathogen control cannot be addressed adequately by nutrient management policies because, along with the uncertainty of pathogen fate and transport under nutrient management regulations, nutrient management policies do not address critical pathogen issues. Using nutrient management policies to control pathogens leaves a number of gaps in important issues that can help to reduce the risk of waterborne-disease outbreaks from land application of livestock wastes. Some of the issues that are overlooked include the use of treatment to reduce microorganism concentrations in stored waste or management practices that reduce microorganism levels in waste, animal health and hygiene, and emerging issues in pathogen control such as the spread of bioaerosols and biosecurity issues. Most of these issues deal with pathogen loads; by minimizing pathogen loads prior to land application, the risk of water pollution can be also be minimized.

Animal Health and Hygiene

Effective pathogen management will begin before manure is even produced. A primary pathway for pathogens to infect farm animals is through their feed source; therefore feed must be kept pathogen-free. Adequate transport and storage of feed will make it less likely for rodents to enter and contaminate it. Rodents have been demonstrated to have a high prevalence of *Cryptosporidium* and *Salmonella* (Rosen, 2000); therefore ensuring they don't have access to the feed will reduce the risk of passing pathogenic diseases onto the healthy animals.

Another management practice in ensuring a healthy herd is to quarantine new and incoming livestock until a veterinarian is able to examine them. A fecal examination may also be required to determine the health status of the animal. Allowing only healthy animals to enter a herd so that illness and disease do not spread throughout the facility is a proactive approach that raises the standards of operations but does not insure that infection will not occur within the herd. Quarantine has also been suggested due to the stress that animals endure during transport. Stress provokes healthy carriers of pathogens to become active carriers and begin shedding organisms at high rates (Clinton et al. 1979).

The overall health of the herd is important in pathogen control since infected animals are not recognizable. A healthy herd will more likely be able to reduce the risk of an outbreak of pathogenic disease. The nutrient management policies reviewed do not discuss the health of the farm animals, whereas in pathogen management, it is one of the first source protection steps.

Pathogen prevalence has been shown to be directly related to the age of the infected species. Age has an effect on the amount of shedding that occurs. In cattle, clinical disease and the shedding of environmentally resistant Cryptosporidium oocysts are usually limited to calves under a few months of age (Atwill, 1995; Pell, 1997; Rosen, 2000). Pathogenic organisms attack immunocompromised or young cattle as they do in humans. Therefore, special care should be taken when handling manure around young animals. As well, if possible, young animals should be restricted from grazing on fields where manure had been applied to reduce the risk of pathogen uptake and infection. Again, the focus on certain species, especially the young, is unique to best pathogen management practices and is not addressed in nutrient management guidelines or regulations. Increased care of young animals is another source protection approach that can reduce the risk of pathogen contamination when handling, storing, or applying manure.

Treatment Effects on Survival of Pathogens in Manure and Slurry

To reduce the risk of pathogen contamination, pathogens must be killed or rendered non-infective. The optimal time to reduce pathogen loads in wastes would be during storage, through desiccation and intense heat. A number of treatment methods have been shown to be effective at reducing the numbers of viable pathogenic organisms in slurry and manure better than conventional methods of storage. Appendix 5.1 shows the details of a number of studies, including survival times of pathogenic organisms when stored in various systems.

Composting and drying have been shown to be effective at decreasing the viability of microorganisms in animal wastes. For example, Vuorinen and Saharinen (1997) studied the effect of manure and straw co-composting in a drum composting system. Dairy cattle and swine manure was mixed with straw (1:2 ratio of manure and straw) and was actively composted for 5-7 days within the drum, a long tube-like composter. The drum controls composting by continuously rotating and aerating the waste. Temperatures in the drum reached 52-62°C. After seven days waste was recovered from the drum and piled, and then turned once a month for 3 months. The researchers indicated that fecal coliforms and fecal streptococci disappeared within the first 7 days in the drum. It was concluded that the thermophilic active composting process in the drum was capable of destroying the populations of bacteria.

Composting has also been shown to reduce *E. coli* O157:H7 and *Salmonella* levels in animal waste. Lung et al (2001) showed that composting of cow manure is less effective at lower temperatures compared to higher temperatures. In this study, 10^7 CFU/g of *S. enteriditis* and *E. coli* O157:H7 were inoculated into cow manure to determine the effect of composting at various temperatures on their viability. It was found that, for both types of bacteria, composting at 25°C had no effect on their levels after 96 hours, whereas composting at 45°C reduced *E. coli* to undetectable levels after 72 hours and *Salmonella* to undetectable levels after 48 hours. Both of these studies are consistent with Jones (1980) who found that when temperatures rose as high as 70°C, bacteria, including *Salmonella* were killed with 5 to 37 days.

Aeration of manure has also proven to reduce numbers of pathogenic organisms more effectively than normal storage conditions. In a study conducted by Munch et al. (1987), selected pathogenic bacteria were seeded in batches of aerated and non-aerated slurry stored in parallel at high (18-20°C) and low (6-9°C) temperatures. Pathogenic bacteria, *E. coli* and fecal streptococci of the slurry flora were all progressively reduced in number during storage in the slurries, and at both temperature levels the inactivation was faster in aerated than in corresponding non-aerated slurry batches. Kudva et al. (1998) also analyzed the survival of *E. coli* O157:H7 in ovine and bovine manure and slurry and the effects of aeration on its survival. It was found that organisms in waste that was aerated did not survive near as long as those in waste that was not aerated. In the non-aerated manure, *E. coli* O157:H7 survived for up to 7 months whereas in the aerated wastes, *E. coli* persisted for only 47 days and 4 months in ovine and bovine manure respectively. They concluded that aeration was effective at decreasing the viability of the microorganisms because of the drying effect of the aeration process. Similarly, Heinonen-Tanski et al (1998) investigated the effects of aeration on *Salmonella* viability in animal slurry. Slurries were stored in glass bottles at controlled temperatures and were aerated with a small pump and mixed. After the pumping and mixing process, no addition of fresh slurry was allowed. This step simulated batch storage management. Aeration took place at a variety of temperatures and proved that temperatures as low as 7.5°C can reduce microorganism levels in waste. This work showed that aeration reduced *Salmonella* levels to below 99% within 2 to 5 weeks in both cattle and pig slurries.

These studies show that improperly incubated or untreated slurry and manure can provide a vehicle for pathogen contamination once applied on land and that treated manure can reduce the likelihood of microbial contamination of water sources, crops or the re-infection of livestock herds.

The use of technology and certain storage systems to kill pathogen loads in manure should be a focus of policies created to control pathogenic contamination of water sources. It is not necessary in nutrient management to take into account the persistence of nitrogen and phosphorous whereas pathogen management must focus on the survival and growth of microorganisms.

According to the Farm Environmental Management Survey that Statistics Canada compiled in 2002, 30% of farm operations in Canada and 26% of farm operations in Ontario currently compost manure. However, only 3% of all farms across Canada aerate their stored wastes and more than 39% in Canada, and 52% in Ontario do not treat their wastes at all(Statistics Canada, 2002). These statistics show that there is a need to address this issue since much of the waste being applied to land has been untreated.

Batch Storage methods

As Heinonen-Tanski et al (1998) suggest, batch storage has been shown to effectively reduce microorganism loads in stored wastes. Batch storage involves storing manures and slurries for a period of time without additions of fresh manure allowing greater die-out and desiccation of pathogenic organisms to occur. Kearney et al. (1993) studied the survival of manure under treatment and in batch storage. The researchers studied the survival of a number of pathogenic organisms in beef cattle slurry in normal storage, batch anaerobic digestion and semi-continuous digestion. It was shown that the time it took to reach T_{90} values for batch anaerobic digestion were less than semi-continuous digestion for both *E. coli* and *Salmonella*. Therefore, batch storage of animal wastes is more effective at reducing viable numbers of pathogens than semi-continuous anaerobic storage.

Batch storage has also been shown to work effectively without the additional effects of treatment. Patni et al. (1984) concur and suggest that the potential for pollution of waters after land application is lower when manures have been stored to reduce microorganisms compared with fresh slurry. Patni et al. (1984) showed that microorganisms had lower T_{90} values when wastes were stored. Both Fenlon et al. (2000) and Ogden et al. (2001) agree that it is advantageous to store waste for a minimum period where no other additions are allowed, in order to maximize the effect of die-off prior to application. Both Munch et al. (1987) and Strauch (1991) suggest that the decimal reduction times (T_{90}) calculated in the existing studies can be used practically to establish advisable batch storage holding times for slurries and solid wastes to reduce the risk of infection once wastes are spread onto the land.

The method of storage has been shown to be an important factor that can reduce pathogen loads and therefore risk of contamination. Storage methods should be addressed in a pathogen management program, however, they are currently not considered under nutrient management policies. Across Canada, 20% of farm operations have no storage facilities for wastes (Statistics Canada, 2002); based on the evidence, application of this amount of fresh waste onto agricultural land increases the risk of waterborne disease outbreaks.

Emerging Issues

Pathogens are disease causing organisms that live by the motto 'only the strong survive', therefore pathogenic organisms such as *E. coli* O157:H7 and *C. parvum* have the ability to adapt and increase their chances of survival in various environments. This ability to adapt has ensured that scientists and researchers must continually monitor changes in levels of virulence, resistance to drinking water treatments and also changes in microorganisms that can cause infection in humans. For example, it was only twenty years ago that *E. coli* O157:H7 was discovered as a human pathogen. This evolution of pathogenic organisms speaks to the need for specific pathogen control in agricultural operations, since emerging pathogens can render other barriers unprotected, such as water treatment plants without a method for treatment until the microorganism is detected and studied. Other security issues in pathogen control include the implementation of biosecurity practices and the spread of pathogens through bioaersols.

Biosecurity Practices:

Since the rate of pathogen incidence in livestock herds can be high, and once a herd is infected the disease can spread quickly due to the close-knit living quarters in agricultural operations, biosecurity needs to be implemented to control this spread in a manner similar to any other disease. Biosecurity is a set of practices that will limit the spread of disease-causing organisms throughout the agricultural operation. Biosecurity practices include restricting human traffic in agricultural operations, disinfecting and cleaning vehicles that may have come from other operations including those of veterinarians and inspectors. Vector minimization can also reduce the spread of disease including rodent and wild bird controls, since these species have been shown to be hosts of pathogenic microorganisms. The reduction of the spread of pathogen infection will reduce pathogen loads and lead to a decreased risk of water contamination.

Bioaerosols:

Bioaerosols have also become a subject of interest and are in fact another pathway for pathogen contamination. Bioaersols are airborne particles consisting of or originating from microorganisms or fragments of microorganisms (Forcier, 2002). Bioaerosols become airborne through the release of dust and water droplets (Forcier, 2002) which can occur during the application of wastes to land when wastes are sprayed at high pressures. Bioaerosols are minute particles that can travel distances in the air and be inhaled by humans or travel to water sources and contaminate water supplies. The issue of pathogenic contamination through bioaersol travel is relatively new; Pillai and Ricke (2002) discuss the issue of bioaerosol creation resulting from animal wastes and note that bioaerosol transport has been shown to occur (Sorber et al. 1984). However, more research is needed to estimate human health risks associated with bioaerosolized pathogens, including the levels of pathogens that could be transported and the dose-response from bioaerosols. In order to prevent pathogen contamination, the issue of bioaerosols as a pathway should be addressed, using nutrient management policies to control pathogens inadequately addresses the issue and reinstates the argument that pathogen are weakly controlled under nutrient management policies.

5.6 Conclusions

Management policies that are designed primarily for sediment and nutrient control may not provide sufficient pathogen control for public health protection. The analysis of the Nutrient Management Act regulations with respect to pathogen fate and transport showed that there is an absence of existing scientific evidence to state with certainty whether the land application regulations of the Nutrient Management Act would adequately control the risk of pathogenic contamination of water sources. The majority of the studies showed that despite tillage and application rates, survival and transport of pathogenic organisms does occur, and occurs differently than for sediments and nutrients. The analysis also showed that there are gaps in pathogenic control when nutrient management policies are applied. For example, the need to promote the health and hygiene of livestock herds is important in pathogen control but irrelevant with respect to nutrient management.

There are a number of risk factors that affect pathogen fate and transport such as high shedding rates of infected animals, their persistence in agricultural environments, their ability to grow in optimal conditions and ability to be transported under a number of management practices, especially in uncontrollable events such as rainfall. These risk factors suggest that pathogen transport and fate, once applied to agricultural land, will always be somewhat uncertain, even if additional research is conducted in this area. These uncertainties are detrimental to public health considering pathogens can cause acute health effects in humans; therefore, in order to minimize this uncertainty and protect public health, pathogens must be addressed prior to land application and cannot be controlled simply as untargeted contaminants under nutrient management policies and regulations.

Chapter Six: Conclusions and Recommendations

6.1 Conclusions

Based on the review of existing scientific studies, nutrient management policies can not be applied to adequately control the risk of pathogen contamination in agricultural environments. It must be noted that the focus of this work, the Ontario Nutrient Management Act, 2002, is only one component in the multiple barrier approach to protect drinking water, the approach that has been highly recommended by Justice O'Connor in the Walkerton Inquiry reports. The multiple barrier approach involves a set of protection measures put in place to guard against contamination of drinking water. The barriers in this approach include source water protection, water treatment, properly maintained and operated water treatment facilities, and comprehensive training of water treatment operators. This work shows the limited effectiveness of one policy designed to protect source waters, the first layer of the multiple barrier approach, and has shown that of the four elements in the approach, it is the element most uncertain in its pathogen abatement effects. Historically, source protection has not been sufficiently utilized in Canadian policies compared to the other barriers in the multiple-barrier approach (Johns, 2000; Federal-Provincial-Territorial, 2002), and will continue to be insufficiently utilized if pathogen management is not more effectively addressed. Pathogen control is not effectively addressed in nutrient management policies based on three important factors:

1. Pathogens have the ability to persist in many agricultural environments. Their prolonged survival allows them to remain viable in the soil matrix until transport occurs, therefore despite tillage and the disruption of macropores or the rate of application, pathogens have survived until transport can take place;
2. Pathogens are transported differently than sediments and nutrients, therefore regulations put in place to control sediments and nutrients can be unsuitable for pathogen control, as was seen in many of the studies that reviewed the effectiveness of vegetated buffer strips; and
3. Nutrient management policies do not address critical pathogen issues such as pathogen load reduction, prevention of the spread of disease and emerging issues such as biosecurity.

The Ontario Nutrient Management Act (2002) is included as part of Ontario's Strategy for Safe Drinking Water. It was legislated primarily to manage nutrients, although the public has assumed that it is also a means of pathogen abatement due to the attention that the Act received after the Walkerton incident, and because this waterborne disease outbreak was in fact caused by a pathogenic bacterium; Escherichia coli O157:H7. The fact that this Act will not effectively perform as a pathogen management measure will be upsetting to those that are most concerned about contamination of drinking water and potential waterborne disease and believe the NMA was developed to minimize the risk of another "Walkerton".

In order to protect source water efficiently, the gap in pathogen management policy must be closed. Pathogen management should be of the utmost importance considering many rural residents in Ontario obtain their drinking water supplies from unfiltered well water sources in highly agricultural areas. A focus on pathogen management will promote practices that are not addressed under nutrient management policies and ensure more effective source protection.

6.2 Recommendations

1. If the goal is to protect pubic health through source protection measures, acutely toxic microbial contamination must be addressed. This will require another effort at creating a set of policies that will enhance the existing level of control to better protect water sources. Pathogen management policies must include agricultural operator education, herd health management and pathogen-load reduction methods during storage in order that the uncertainties in fate and transport of pathogens after land-application of wastes are minimized. The key to a successful pathogen management policy is to focus on the survival of microorganisms in the waste prior to land application.
2. Since testing for pathogenic organisms is very expensive and requires training, and since herd infections are episodic in nature and could be missed if testing were not conducted regularly, policy makers and agricultural operators must assume that all livestock wastes contain pathogenic materials at normal shedding concentrations. Following the precautionary principle and assuming risk will ensure that wastes are handled appropriately and with caution at all times and will increase control of microbial contamination.
3. The probability that pathogens will survive in a prescribed waste and be transported to a human water source depends on a number of variables as reported in this study. A

risk assessment approach can be applied to determine the greatest agricultural risk sources, the probability of pathogen survival and the possibility of transport to water sources. However, as this research has shown, there are gaps in the knowledge needed to establish reliable probabilities.

4. This study should be repeated with a focus on viral fate and transport in agricultural operations, including enteroviruses, rotaviruses, and Norwalk-like viruses, to assess the current control of viral contamination since these organisms are also prevalent in agricultural wastes and are also currently remain as untargeted contaminants.
5. The existing knowledge of managing the microbial risk of livestock waste is lacking and therefore further research should be conducted so that pathogen management policies can be created based on sound scientific knowledge.

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Appendices

Appendix 2.1: Cross-transmission potential between animals and humans for Cryptosporidiosis.

Animal	Prevalence of infection in animals	Evidence for Transmission	
		Animal to humans	Humans to animal
Dogs	1.4-45%	No	Yes
Cats	1.3-87%	Yes[a]	Yes
Cattle[b]	17-76%	Yes[a]	Yes
Dairy Calves	50%	Yes	Yes
Sheep	78%	No	No (not tested)
Goats	-[c]	No	No (not tested)
Deer	92%[d]		
Pigs	5.3%	Yes[a]	Yes
Horses	16%	No	No (not tested)
Raccoons	13%	No	No (not tested)
Mice	30%	No	Yes
Rats	-[c]	No	Yes
Rabbits	8%	No	No (not tested)
Chickens[e]	5.9-27%	No	No
Ducks[f]	88%	No	No

(Source: Rose, J.B. 1997)

a: Epidemiological evidence.

b: Over 15 studies, antibody prevalence indicating infection is 50% in calves and >90% on farms.

c: Infection prevalence is unknown.

d: High prevalence in farmed deer, unknown in the wild.

e: Also found in turkeys, ducks, pheasants, quail and geese.

f: At duck farms

Appendix 3.1: Summary of Canadian Policies and Strategies Reviewed

Province	Legislation	Act/Reg/Guide	Date	Summary
British Columbia	Agricultural Waste Control Regulation	Reg 131/92. Part of the Waste Management Act and the Health Act.	April 1, 1992	Farmers are exempt from the WMA provided that they comply with the Code of Agricultural Practice for waste management.
	Drinking Water Protection Act	Act	Passed 3rd reading on April 11th 2001	The drinking water action plan is based on eight key principles for safe drinking water, which focus on preventing contamination, and identifying potential risks and appropriate water quality improvements.
Alberta	Agricultural Operations Practices Act	Regulation 267/2001		This Act provides the institutional framework for resolving conflicts between agricultural producers and the urban/rural non-farmers. Under the Act, farmers using generally accepted practices and not contravening the land use bylaws of the municipality in which the operation is located, are not liable in a nuisance lawsuit and cannot be prevented from carrying on their operation because it causes or creates a nuisance.
	Water Act	Regulation 205/98	1998	The Province's review of its water management policy and legislation began in 1991 with the view of updating its water management policy and legislation to ensure that Alberta's water is managed and conserved for today and for the future. The *Water Resources Act* was over 60 years old and was primarily a tool for allocating water. The new Act focuses on managing and protecting Alberta's water and on streamlining administrative processes.
Sask.	Agricultural Operations Act	Regulation 34/97	1995	This Act requires waste storage and management plans for ILOs. There are 3 definitions for ILOs including any operation with 20 animal units or more that is within a certain distance of either an open body of water or domestic water well.
	Establishing and Managing Livestock Operations Guidelines	Guidelines	2001	This document describes normally accepted practices for establishing and managing livestock operations. SAFRR has tried to balance the competing interests of agricultural producers and their neighbours, as well as reconciling the regional and cultural differences that exist within the province.

Manitoba	Livestock Manure and Mortalities Management Regulation	Regulation 42/98	March 30, 1998	This regulation under the Environment Act was adopted in 1998 after a review of the Livestock Waste Regulation that was then in effect. The purpose of this regulation is to prescribe requirements for the use, management, and storage of livestock manure and mortalities in agricultural operations so that livestock manure and mortalities are handled in an environmentally friendly manner.
	Proposed Nutrient Management Strategy for Manitoba's Surface Water	Proposed by Manitoba Conservation	May 7, 2002	Manitoba Conservation has responded to the nutrient enrichment issue by identifying the need for the development of a long-term Nutrient Management Strategy for the province and beginning to work towards this strategy.
Quebec	Regulation Respecting Agricultural Operations	Regulation; Environment Quebec	June 15, 2002	The Regulation respecting agricultural operations in effect as of June 15, 2002, addresses livestock facilities and manure management. It replaces the Regulation respecting the reduction of pollution from agricultural sources. The information that I have is incomplete b/c I have what is only written in English.
New Brunswick	Regulation 99-32 under the Livestock Operations Act	Regulation 99-32	May 1, 1999	The Livestock Operations Act and the regulations under the Act, establish a framework for a licensing system that is being put in place to ensure that the livestock industry in the province develops in an environmentally responsible manner.
	Wellfield Protected Area Designated Order under the Clean Water Act	Regulation 2000-47	October 1, 2000	The purpose of this regulation is to ensure that portions of the ground water recharge areas that are used as sources of water for a public ground water supply, are designated as protected areas. This is an innovative source protection regulation.
	Manure Management Guidelines	Guidelines	February 1, 1997	The Manure Management Guidelines for NB have been developed by the Land Development Branch, NB Department of Agriculture, Fisheries, and Aquaculture in consultation with other government agencies and farm organizations. The users of these guidelines are cautioned that they are based on minimal recommended practices, or better.
Nova Scotia	Animal Manure and Use Guidelines	Guidelines	1991	The purpose of the guidelines is to create an awareness of animal manure as a valuable fertilizer source and soil amendment, while providing instruction in environmental protection.
	Siting and Management of Hog Farms in Nova Scotia	Guidelines		The objectives of these guidelines are to: 1) Provide info and guidance to farmers, on how to manage hog farms in an environmentally acceptable manner. 2) Provide municipalities with info on acceptable management practices and siting guidelines for hog farms, which may be incorporated into municipal bylaws, and 3) Provide stakeholders, including hog farmers, planner, environmental groups, and financial institutions, with guidelines to assess the siting and management of hog farms.

Prince Edward Island	Guidelines for Manure Management in PEI	Guidelines	January 7, 1999	These guidelines for manure management recognize the importance of the livestock industry to the social and economic well being of PEI. The guidelines support the principles that livestock operations have an important role to play in Island society, and hence have a right to establish, operate and expand in accordance with reasonable and acceptable standards.
NWT	Guidelines for Agricultural Waste Management	Guidelines	May 1999	The purpose of these Guidelines is to establish clear and consistent waste management standards for the NWT' intensive livestock and agricultural industry. They are intended to increase awareness of agricultural waste management, provide direction for the management of wastes from intensive livestock facilities, and protect the environment.

Appendix 3.2: Summary of United States Policies and Strategies Reviewed

State	Legislation	Act/Reg/Guide	Date	Summary
Washington	Chapter 90.64 RCW: Dairy Nutrient Management Act	Act under Department of Ecology	1998	This legislation overhauled the State's dairy waste program, creating the DNMA from the previous Dairy Waste Management Act, Chapter 90.64 RCW. In this act all dairies in the state are required to register with the Department of Ecology and prepare and implement a dairy nutrient management plan. The required NMPs have to use the practice standards of the Natural Resources Conservation Service of the USDA.
	Manure Management Guidelines for Western Washington	Guidelines funded by the Department of Ecology and the Centennial Clean Water Funds.	April 1995	This document was designed to help the agricultural community meet existing regulations. It provides operators with information on farm management practices that protect both surface and ground water. These guidelines will help managers develop, implement, and monitor a NMP.
Iowa	Chapter 65 of the Iowa Administrative Code: Animal Feeding Operations	Statute of Iowa Law that is monitored by the Iowa Department of Natural Resources	1999	Iowa law requires that all manure from animal feeding operations must be land applied in a manner that will not cause surface or groundwater pollution. Chapter 65 contains rules that govern land application of manure.
Missouri	Guide to Animal Feeding Operations	Department of Natural Resources Guidelines	1999	By establishing and enforcing standards and properly managing animal waste, we can protect our valuable water resources. Preventing contamination is the key to protecting water quality for all Missouri citizens.
Wisconsin	Chapter NR 151: Runoff Management	Department of Natural Resources	October 2002	Runoff Management defines agricultural performance standards and prohibitions, non-agricultural performance standards, transportation facility performance standards and a process for the development and dissemination of non-agricultural technical standards.
	Chapter NR 243: Animal Feeding Operations	Department of Natural Resources	October 2002	Animal Feeding Operations: adds the NR 151 performance standards and prohibitions to the Manure Management Program.
	Guidelines for Applying Manure to Cropland and pasture in Wisconsin	Guidelines written by Fred Madison, Keith Kelling, Leonard Massie, and Laura Ward Good of the University of Wisconsin		Proper manure management and handling is complicated. This publication describes how to maximize manure's benefits to plants and soils and to minimize the possibility of surface or groundwater pollution from manure applications. The guidelines described provide the basis for developing an economically and environmentally-sound manure-management plan.
Minnesota	Minnesota Rules: Chapter 7020: Feedlot Rules	Regulations enforced by the Minnesota Pollution Control Agency	2000	This chapter governs the storage, transportation, disposal and utilization of animal manure and process wastewaters and the application for and issuance of permits for construction and operation of animal manure management and disposal or utilization systems for the protection of the environment.

Michigan	Generally Accepted Agricultural and Management Practices for Manure Management and Utilization.	Guidelines adopted by the Michigan Agriculture Commission of the Department of Agriculture.	Feb 2002	These GAAMPs for Manure Management and Utilization are scientifically-based and have been developed to provide nuisance protection for farm operations and environmental protection for soil, surface water, groundwater, and air resources.
Maine	Nutrient Management Act/ Nutrient Management Rules	Maine Department of Agriculture, Food, and Rural Resources.	March 1998	This Act regulates how manure is managed and used on farms.
Texas	Chapter 321 Subchapter B: CAFOs Rules	Texas Natural Conservation Commission	July 1999	The rules implemented by TNRCC are designed to protect the quality of the state's air and water resources. All concentrated animal feeding operations located in the state, regardless of size, are required to comply with the provisions of Chapter 116, Chapter 321, Subchapters B.
Delaware	Delaware Nutrient Management Law (Chapter 22 of Delaware Agriculture Title III Code)	Delaware Department of Agriculture		The purposes of this chapter are: • To regulate those activities involving the generation and application of nutrients in order to help improve and maintain the quality of ground and surface waters and to meet or exceed federally mandated water quality stds • To establish a certification program that encourages the implementation of BMPs in the generation, handling, or land application of nutrients in Delaware. • To establish a NM planning program • To formulate a systematic and economically viable NM program that will both maintain agricultural profitability and improve water quality in Delaware

	Delaware Nutrient Management Program	Delaware Nutrient Management Commission of the Delaware Department of Agriculture	June 1999	To manage those activities involving the generation and application of nutrients in order to help maintain and improve the quality of Delaware's ground and surface waters and to help meet or exceed federally mandated water quality standards, in the interest of the overall public welfare. Included in the program are BMPs for nutrient management, the Nutrient Management Relocation Program, and a Guideline for the development of a NMP.
Nebraska	LB 1209: The Livestock Waste Management Act	Nebraska Department of Quality	April 1998	The goal of the Livestock Waste Control Program is to protect the state's groundwater and surface water for pollution resulting from improper livestock waste disposal.
	Title 130: Rules and Regulations Pertaining to Livestock Waste Control	Nebraska Department of Quality	1972, and updated anytime new livestock-legislation is passed.	Calving operations holding cattle less than ninety days per year are exempt from Title 130 requirements. The Livestock Program administers and enforces Title 130. The Title 130 Regulations are based on the Livestock Waste Management Act and all other livestock-related legislation that has been passed by our state legislature since about 1972. Whenever new legislation passes (not too often, actually), Title 130 is updated to reflect the changes.

Appendix 3.3: Summary of Other Policies and Strategies Reviewed

Country	Legislation Name	Act/Reg/Guide	Date	Summary
England	The Code of Practice for the Prevention and Control of Salmonella on Pig Farms	Guideline under the DEFRA	1999	A set of preventive measures that deal specifically with the control of bacteria and disease in an agricultural setting.
	The Code of Good Agricultural Practice for the Production of Water.	A Statutory Code under Section 97 of the Water Resources Act 1991 under DEFRA.	1998	This Code aims to provide a practical guide to farmers and growers to help prevent them from creating water pollution.
Finland	Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters. Pursuant to Section 11 of the Environmental Protection Act.	Law under the Ministry of the Environment.	Nov 15 2000	This is an action program concerning the protection of waters against pollution caused by nitrates from agricultural sources.
Netherlands	Dutch Approach to Reduce the Mineral Surplus and Ammonia Volatilization	Law		The Dutch government combats environmental pollution caused by manures and fertilizers through a policy of environmental targets.
Scotland	Prevention of Environmental Pollution from Agricultural Activity	Law under the Scottish Office Agriculture Environment and Fisheries Department	1997	To provide farmers and crofters and those involved in farming activities, such as agricultural contractors and companies involved in spreading organic manures to land, with practical guidance on how to prevent pollution.
	The Control of Pollution (Silage, Slurry, and Agricultural Fuel Oil) (Scotland) Regulations 2001	A Scottish Statutory Instrument	July 1, 2001	

Appendix 3.4: New Brunswick NMP and Manure System Descriptions

The required Manure Nutrient Management Plans (MNMPs) must include the following:
A) When the manure is to be applied to land by or on behalf of the applicant:

- Location of application
- Timing of application
- Frequency of application
- Method of application
- Rate of application
- The level of available nutrients in the manure and in the soil.
- A description of the topography of the land including slope, location, to watercourses, wetlands, and other water sources.
- The maximum nutrient applications that are proposed.

B) When the manure is not to be applied to land by or on behalf of the applicant:

- A copy of the agreement of removal of the manure and the frequency of the removal.
- A plan for the proposed treatment of the manure and the intended disposal of the resulting product.

The required Manure System description must include:

- The proposed system of collection and transfer of manure to storage.
- Type of storage.
- Any proposed management practices affecting manure production and its characteristics.
- Proposed transport method of manure to application site.
- Any proposed treatment of manure prior to land application.
- Any proposed uses for manure other than land application.
- A proposed emergency plan in case of failure of any part of the system.

Appendix 3.5: Summary of Storage Regulations and Guidelines in Canada

	British Columbia		Alberta		Sask.		Manitoba		Que.	New Brunswick			Nova Scotia		PEI	NWT
	Agricultural Waste Control regulation	Drinking Water Protection Act	Agricultural Operations Practices Act	Water Act	Agricultural Operations Act	Livestock Operations Guidelines	Livestock Manure and Mortalities	Proposed NMS for Surface Water	Regulation Respecting Agricultural Operations	Livestock Operations Act Reg. 99-32	Wellfield Protected Areas	Manure Management Guidelines	Animal Manure and Use Guidelines	Siting and Management of Hog Farms	Guidelines for Manure Management	Guidelines for Agricultural Waste
STORAGE								[35]			[36]					
Require a plan/permit?					YES[37]		YES				YES		YES[38]			
Location from:										[39]		[40]		[41]		
-watercourses	15m		30m or >[42]				100m		15m				100m	100m		100m

[35] Once the boundaries have been set, part of the process of completing a plan will be to identify all of the inputs into the river system within a basin or watershed, followed by the development and implementation of strategies aimed at reducing these inputs, where required. These strategies may include spreading, storage, and tillage requirements of any activity that puts nutrients into the soils and watercourses of the area.

[36] Each Zone is restricted in the allowable amount of storage of various manures and fertilizers. (C>B>A).

[37] Manure Storage plans must include specific details that follow normally accepted agricultural practices that are laid out in the Livestock Operations Guidelines for Saskatchewan.

[38] Farm operators should obtain a manure handling system design from the NS Department of Agriculture and Marketing Extension Services agricultural engineers. The system plan will incorporate farm resource considerations including economics, manpower, and equipment, existing structures, animal populations, site characteristics and storage capacity.

[39] See Appendix 3.8

[40] See Appendix 3.9

[41] See Appendix 3.10

[42] This MSD does not apply if the owner or operator demonstrates to the Board, before the facility or area is constructed that, a) the natural drainage from the facility or area is away from the common body of water, or b) a berm or other secondary protection for the common body of water constructed by the owner or operator protects the common body of water from contamination.

	British Columbia		Alberta		Sask.		Manitoba		Que.	New Brunswick			Nova Scotia		PEI	NWT
	Agricultural Waste Control regulation	Drinking Water Protection Act	Agricultural Operations Practices Act	Water Act	Agricultural Operations Act	Livestock Operations Guidelines	Livestock Manure and Mortalities	Proposed NMS for Surface Water	Regulation Respecting Agricultural Operations	Livestock Operations Act Reg. 99-32	Wellfield Protected Areas	Manure Management Guidelines	Animal Manure and Use Guidelines	Siting and Management of Hog Farms	Guidelines for Manure Management	Guidelines for Agricultural Waste
-domestic water supply	30m		100m				100m						100m	100m	Base of 90m[43]	100m
-property boundaries							100m			20m			50m	50m		[44]
-nearest residence			150m										50m			
Construction Requirements			liner				Liner and[45]		Water-tight				Man. tight		VBZ and[46]	
Volume Requirements	Not specific		9 mths			6 mths			6 mths	210 days after Nov 1		210 days after Nov1	7 mths	7 mths	7 mths on Nov1[47]	8 mths
Earthen Storage Facility																
-construction requirements			Side slope of 3:1									YES[48]				

[43] Additional separation is based on a PEI County Soil Survey and the concerns regarding mobility in certain soils.
[44] See Appendix 3.11
[45] There are special construction requirements for coarse sands, gravel, and fractured rock.
[46] Liquid and semi-solid manure storages must be designed and constructed according to the structural and safety requirements of the Canadian Farm Building Code.
[47] The storage capacity of 7 months is for the accumulation of liquid manure. Solid manure storage should allow for a minimum of 60 days accumulation of manure in combination with field storage. If field storage is not an option, then a 210 day storage at the barn is recommended.

	British Columbia		Alberta		Sask.		Manitoba		Que.	New Brunswick			Nova Scotia		PEI	NWT
	Agricultural Waste Control regulation	Drinking Water Protection Act	Agricultural Operations Practices Act	Water Act	Agricultural Operations Act	Livestock Operations Guidelines	Livestock Manure and Mortalities	Proposed NMS for Surface Water	Regulation Respecting Agricultural Operations	Livestock Operations Act Reg. 99-32	Wellfield Protected Areas	Manure Management Guidelines	Animal Manure and Use Guidelines	Siting and Management of Hog Farms	Guidelines for Manure Management	Guidelines for Agricultural Waste
Field Storage:									[49]							
Time allowed	[50]															
Construction requirements	berms															
MSDs from:																
-watercourse							100m		150m						90m[51]	
-ditches									15m							
Underpen Storage:																
Time allowed	9 mth															
MSDs from:																
-watercourse	15m															
-wells	30m															
Non-normal Conditions	Rainy seas. [52]		Fl. level[53] Catch basin [54]				[55]									

[48] Requirements include diversion of water, seepage control measures, berms, minimum depth to bedrock, minimum depth to water table, and distance to subsurface drains.
[49] Requirements of field storage include that the ground surface must be covered with vegetation, the surface must not have a slope >5%, and the field storage pile cannot remain in the same location for two years in a row.
[50] Storage in the field can only be piled for 2 weeks, but if they are greater than 30m away from a watercourse they can remain for 9 months.
[51] If the watercourse is a public watercourse the MSD increases to 300m.

[52] In areas of the Province, including the Fraser Valley and Vancouver Island, that receive a total average precipitation greater than 600mm (24 inches) during the months of October to April inclusive, field stored solid agricultural wastes, except agricultural vegetation waste, must be covered from October 1 to April 1 inclusive to prevent the escape of agricultural waste that causes pollution.

[53]No part of the storage facility must be less than 1 m below any part of the facility to avoid run on. Additionally, operators must include erosion control measures that can protect the facility from erosion, runoff, run-on and flooding.

[54] A constructed catch basin for runoff control must have a storage capacity that can accommodate at least a one day rainfall that has a 1:30 probability, as calculated based on various locations across the province.

[55] No person shall locate a manure storage facility within the boundaries of the 100 year flood plain elevation, unless, in the opinion of the director, satisfactory flood protection of the facility exists.

Appendix 3.6: Summary of Storage Regulations and Guidelines in the United States

	Washington		Iowa	Mo.	Wisconsin			Minn.	Mich.	Maine	Texas	Delaware	Nebraska	
	Dairy Nutrient Management Act	Manure Management Guidelines for Western Washington	Chapter 65: Animal Feeding Operations	Guide to Animal Feeding Operations	NR 151: Runoff Management	NR 243: Animal Feeding Operations	Guidelines for Applying Manure	Minnesota Rules: Chapter 7020: Feedlot Rules	GAAMPs for Manure Management and Utilization	Nutrient Management Act/ Regulations	Chapter 321 Subchapter B: CAFOs Rules	Nutrient Management Law Nutrient Management Program	Livestock waste Management Act	Title 130: Rules and Regulations
STORAGE										[56]				
Location of Storage Facility from:			[57]											
-watercourse	91.44 m		Major: 152.4m Minor: 60.96m											
-wells	91.44 m		Deep: 30.48m Shall.: 60.96m	91.44 m				Public: 304.8m Private: 30.48m		30.48m	Public: 152.4 m Private 45.72		30.48m[58]	Public: 304.8m Private: 30.48m
-seasonal high groundwater level				>1.22 m										>1.22m
-nearest residence				[59]										

[56] Nutrient Management Plans must be developed or approved by a certified Nutrient Management Planner. The NMPs are very site specific and spreading MSDs are determined based on topography, crop, location of water sources etc... The only minimum separation distance required on every operation is that storage facilities must be at least 30.48m from any domestic wells.

[57] See Appendix 3.12: Required Separation Distances for Manure Storage Structures in Iowa.

[58] The department shall not issue a permit for an existing livestock waste control facility which is located within 30.48m of a well if the water well is under separate ownership and water from the well is used primarily for human consumption.

	Washington		Iowa	Mo.	Wisconsin			Minn.	Mich.	Maine	Texas	Delaware	Nebraska	
	Dairy Nutrient Management Act	Manure Management Guidelines for Western Washington	Chapter 65: Animal Feeding Operations	Guide to Animal Feeding Operations	NR 151: Runoff Management	NR 243: Animal Feeding Operations	Guidelines for Applying Manure	Minnesota Rules: Chapter 7020: Feedlot Rules	GAAMPs for Manure Management and Utilization	Nutrient Management Act/ Regulations	Chapter 321 Subchapter B: CAFOs Rules	Nutrient Management Law Nutrient Management Program	Livestock waste Management Act	Title 130: Rules and Regulations
Construction Requirements	YES	YES[60]	YES		0.305m free-board[61]						YES	YES		YES
Volume Requirements		180-240 days				[62]				180 days				180 days
Earthen Storage Facility			YES	YES		YES			YES		YES	YES		
-construction requirements			0.61m free-board			Liner soil must be tested.			Liners.		YES			
MSDs														
-wells			Public: 304.8m Others: 121.9m	91.44 m										
-tile drainage lines			15.25m											

[59] Minimum separation distances from storage structures to any public buildings or residences: 304.8m for Class 1C (1,000-2,999 AU), 609.6m for Class 1B (3,000-6,999 AU), and 914.4m for Class 1C (>7,000 AU).
[60] Construction requirements include a concrete floor and stacking structure
[61] Or adequate freeboard storage to the equivalent volume of a 25-year, 24-hour storm, whichever is greater.
[62] Capacity depends on approved MMP.

	Washington		Iowa	Mo.	Wisconsin			Minn.	Mich.	Maine	Texas	Delaware	Nebraska	
	Dairy Nutrient Management Act	Manure Management Guidelines for Western Washington	Chapter 65: Animal Feeding Operations	Guide to Animal Feeding Operations	NR 151: Runoff Management	NR 243: Animal Feeding Operations	Guidelines for Applying Manure	Minnesota Rules: Chapter 7020: Feedlot Rules	GAAMPs for Manure Management and Utilization	Nutrient Management Act/ Regulations	Chapter 321 Subchapter B: CAFOs Rules	Nutrient Management Law Nutrient Management Program	Livestock waste Management Act	Title 130: Rules and Regulations
-groundwater			>1.22m or 0.61m with liner											
-bedrock			>1.22m 3.05m is recom.											
Earthen Storage Capacity			420 days											
Field Storage:				YES	Not in WQMA [63]	No[64]		YES[65]	YES			YES		
Time allowed								Max. 365 days				180days		
MSDs from:														

[63] Water Quality Management Area: the area within 304.8m from the ordinary high water mark of navigable waters that consist of a lake, pond, or flowage, or a site that is susceptible to groundwater contamination. A site susceptible to groundwater contamination means 1) an area within 76.2m of a private well, 2) an area within 304.8m of a municipal well, 3) an area within 91.44m upslope or 30.48m downslope of karst features, 4) a channel with a cross-sectional area equal to or greater than 3 square feet that flows to a karst feature, 5) an area where the soil depth to groundwater or bedrock is less than 0.61m, and 6) an area where the soil does not exhibit one of the following a) at least a 0.61m soil layer with 40% fines or greater above groundwater and bedrock, b) at least a 0.91m soil layer with 20% fines or greater above groundwater or bedrock, and c) at least a 1.52 soil layer with 10% fines or greater above groundwater and bedrock.

[64] Not unless the operator has written approval

[65] But is prohibited on land with > 6% slope or where the soil texture is coarser than sandy loam.

	Washington		Iowa	Mo.	Wisconsin			Minn.	Mich.	Maine	Texas	Delaware	Nebraska	
	Dairy Nutrient Management Act	Manure Management Guidelines for Western Washington	Chapter 65: Animal Feeding Operations	Guide to Animal Feeding Operations	NR 151: Runoff Management	NR 243: Animal Feeding Operations	Guidelines for Applying Manure	Minnesota Rules: Chapter 7020: Feedlot Rules	GAAMPs for Manure Management and Utilization	Nutrient Management Act/ Regulations	Chapter 321 Subchapter B: CAFOs Rules	Nutrient Management Law Nutrient Management Program	Livestock waste Management Act	Title 130: Rules and Regulations
-watercourse					Lake: 304.8m Stream: 91.44m			15.25m				30.48m		
-wells				91.44 m	Private: 76.20m Public: 304.8m			30.48m		30.48m				
-ditches								91.44m				30.48m		
-high water table								0.61m						
-public road												30.48m		
-residence												60.96m		
Roof Water Management		YES									YES	YES		
Non-normal Conditions		[66]	[67]											

[66] An extra month's capacity for abnormal weather conditions.

[67] If site topography, operation procedures, experience, or other factors indicate that a greater or lesser level of manure control than that specified is required to provide an adequate level of water pollution control for a specific animal feeding operation, the department may establish different minimum manure control requirements for that operation.

Appendix 3.7: Summary of Storage Regulations and Guidelines in Other Countries

	England	Finland	Netherlands	Scotland	
	Code of Good Agricultural Practice for the Production of Water	Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters.	Manure and Fertilizer Policy	PEPFAA Code of Practice	The Control of Pollution (Silage, Slurry, and Agricultural Fuel Oil) (Scotland) Regulations 2001
STORAGE					
Location of Storage Facility from:					
-watercourse	10m	10m		10m	10m
-wells				50m	
-property boundaries					
-field drain	10m			10m	
-nearest residence				As far away as possible.	
Length of Storage	[68]			[69]	
Construction Requirements	BS 5502 – 1993. Floor must be impermeable.	Water-tight		[70]	Must be impermeable.
Volume Requirements	4 months of slurry and rainfall.	12 months, unless selling some of it to another operation.	6 months	6 months	6 months
Earthen Storage Facility	Allowed	Allowed		Allowed	Allowed
-construction requirements					750mm of freeboard
MSDs					
-watercourses	10m				
-well					

[68] If Cryptosporidium parvum has been diagnosed then slurries should be stored for as long as possible before spreading, and solid manure should be stored for at least two months.
[69] If Cryptosporidium parvum has been diagnosed then slurries should be stored for as long as practicable before spreading, and solid manure should be stored for at least two months.
[70] Maintain a freeboard of at least 0.3m, for above ground slurry stores and, 0.75m for slurry lagoons.

	England	Finland	Netherlands	Scotland	
	Code of Good Agricultural Practice for the Production of Water	Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters.	Manure and Fertilizer Policy	PEPFAA Code of Practice	The Control of Pollution (Silage, Slurry, and Agricultural Fuel Oil) (Scotland) Regulations 2001
-tile drainage lines	10m				
-groundwater					
-bedrock					
Treatment				[71]	
Field Storage:		[72]			YES
Time allowed					
Construction requirements		[73]			
MSDs from:					
-watercourse	10m	100m		10m or field drain	
-wells	50m	100m		50m	
-ditches	10m	Main: 100m, Small: 10m			
-public road					
-residence not located on operator's property					
Storage basins for runoff control.					
Roof Water Management				YES	
Non-normal Conditions	Cryptosporidium[74]			Cryptosporidium[75]	

[71] Please see Appendix 3.13: Waste Treatment Technology in the PEPFAA.

[72] Field storage is only allowed after the manure has been composted for at least 3 months and has a dry matter content of at least 30%. It also must be sited away from areas that become flooded or in areas above groundwater.

[73] Construction requirements of a field pile include a mud or peat layer 15 cm thick that must be spread at the bottom of the heap in order to catch nutrient runoff. The field pile must covered by a tarpaulin, and piling manure in the same place every year must be avoided.

[74] On farms where Cryptosporidium has been diagnosed, extra precautions should be taken to decrease the risk of contaminating watercourses with viable Cryptosporidium parvum oocysts. Precautions include: storing slurries for as long as practicable before spreading, and storing farmyard manure for up to 2 months before spreading.

[75] On farms where Cryptosporidium has been diagnosed, extra precautions should be taken to decrease the risk of contaminating watercourses with viable Cryptosporidium parvum oocysts. Precautions include: storing slurries for as long as practicable before spreading, and storing farmyard manure for up to 2 months before spreading.

Appendix 3.8: Livestock Facility/Storage Facility MSD formula for Regulation 99/32 of New Brunswick

Minimum Separation Distance: A*B*C		
A=500m	B = the manure factor	C = the livestock factor
Manure Factor		
Manure Type	**Manure Storage System**	**Manure Factor**
Solid	In situ	0.7
Solid	Open pile	0.8
Liquid or semi-solid	Covered non-earthen tank	0.8
Liquid or semi-solid	Open non-earthen tank	0.9
Liquid or semi-solid	Open earthen tank	1.00
Livestock Factor		
Class of Livestock	**Type of Housing**	**Livestock Factor**
Caged layers	Manure stored in a barn	1.5
Pullets	Caged (manure stored in barn)	1.5
Fox		1.5
Mink		1.5
Pigs		1.5
Veal calf (white veal)		1.5
All other livestock		0.75

Appendix 3.9: MSD Calculation for Siting Livestock Facilities in the Manure Management Guidelines in New Brunswick.

The MSD calculation requires the base distance (A), expansion factor (B), manure system factor (C), and livestock factor (D) from Tables F-2, F-3, F-4 and F-5 respectively.

Table 1: Minimum Separation Distances:

	MSD
Nearest neighbouring dwelling	A*B*C*D
Residential, commercial or recreational areas	2*A*B*C*D
Public Buildings	3*A*B*C*D
Right of way of arterial or collector highway	50m
Property Line	20m
Watercourse	100m
Designated watershed/wellfield	Special permission required

Table 2: Base Distance as a function of number of animal units (A)

Animal Units	Base Distance (m)
0-100	300
101-200	400
201-300	475
301-400	550
401-500	600
501-600	650
>600	700

Table 3: Expansion factor as a function of % increase (B)

% Increase*	Expansion Factor
0-50	0.7
51-75	0.77
76-100	0.83
101-150	0.91
151-200	0.97
201-300	1.04
301-400	1.08
401-500	1.11
>500	1.14
New Operations	1.16

* % Increase = ((Proposed AU – Present AU)/ Present AU) * 100

Table 4: Manure System Factor (C)

Manure System	Factor
Dry litter in-situ	0.7
Solid open manure pile	0.8
Semi-solid or liquid covered concrete tank	0.8
Semi-solid of liquid open concrete tank	0.9
Semi-solid or liquid uncovered earthen storage	1.0

Table 5: Livestock Factor based on livestock class and housing type (D)

Class of Livestock	Type of Housing	Livestock Factor
Beef	Barn confinement	0.7
Beef	Barn with yard	0.8
Caged Layers	Manure stored in barn	1.0
Caged Layers	Manure removed daily	0.8
Chicken breeder layers		0.8
Chicken broilers/roasters		0.65
Pullets		0.7
Dairy Cows	Tie stall	0.65
Dairy Cows	Free stall	0.7
Dairy Heifers	Barn confinement	0.7
Dairy Heifers	Barn with yard	0.8
Foxes		1.1
Goats		0.7
Horses		0.65
Minks		1.1
Rabbits		0.8
Sheep		0.7
Swine		1.0
Turkeys		0.7
Veal		1.0

Appendix 3.10: Separation Distances from the Hog Barn or Manure Storage in Siting and Management of Hog Farms in Nova Scotia

Size of Operation	Off-Farm Dwelling (m)	Property Line (m)	Non Farm Development (m)	Public Road (m)	Off-Farm Well or Any Watercourse
1-100	300	50	600	50	100
101-200	350	50	600	50	100
201-300	400	50	600	50	100
301-400	450	50	600	50	100
401-500	500	50	600	50	100
501-600	600	50	600	50	100
601-700	700	50	700	50	100
701-800	800	50	800	50	100
801-900	900	50	900	50	100
900 and over	1000	50	1000	50	100

Appendix 3.11: Separation Requirements of Storage Facilities from Populations in the NWT (m).

	Animal Units					
Population	10-50	50-300	300-500	500-2000	2000-5000	>5000
Single Rural Residence	300 *450*	300 *450*	400 *600*	800 *1200*	1200 *1600*	1600 *2000*
<100	400 *600*	400 *600*	800 *1200*	1200 *1600*	1600 *2000*	2000 *2400*
100-500	400 *600*	800 *1200*	1200 *1600*	1600 *2000*	2400 *2400*	2400 *2400*
500-5000	800 *1200*	1200 *1600*	1600 *2000*	2400 *2400*	3200 *3200*	3200 *3200*
>5000	800 *1200*	1600 *2000*	2400 *2400*	3200 *3200*	3200 *3200*	3200 *3200*

NOTE: numbers in italics are for open liquid manure storage.

Appendix 3.12: Required Separation Distances for Manure Storage Structures in Iowa.

DISTANCES TO BUILDINGS AND PUBLIC USE AREAS

Type of Structure	**Animal Weight Capacity (lbs.)**		**Residences, Businesses, Churches, Schools**		**Public Use Areas**
	Swine, Sheep, Horses, and Poultry	Beef and Dairy Cattle	**Unincorporated Areas**	**Incorporated Areas**	
Anaerobic lagoons and uncovered earthen manure storage basins	<200,000	<400,000	381m	381m	381m
	200,000-<625,000	400,000-<1,600,000	381m	381m	381m
	625,000-<1,250,000	1,600,000-4,000,000	571.5m	571.5m	571.5m
	1,250,000 or more	4,000,000 or more	762m	762m	762m
Covered earthen manure storage basins	<200,000	<400,000	304.8m	381m	381m
	200,000-<625,000	400,000-<1,600,000	304.8m	381m	381m
	625,000-<1,250,000	1,600,000-4,000,000	381m	571.5m	571.5m
	1,250,000 or more	4,000,000 or more	571.5m	762m	762m
Uncovered formed manure storage structures	<200,000	<400,000	None	None	None
	200,000-<625,000	400,000-<1,600,000	304.8m	381m	381m
	625,000-<1,250,000	1,600,000-4,000,000	381m	571.5m	571.5m
	1,250,000 or more	4,000.000 or more	609.6m	762m	762m
Confinement buildings and covered formed manure storage structures	<200,000	<400,000	None	None	None
	200,000-<625,000	400,000-<1,600,000	381m	381m	381m
	625,000-<1,250,000	1,600,000-4,000,000	571.5m	571.5m	571.5m
	1,250,000 or more	4,000,000 or more	762m	762m	762m
Egg wash-water storage structures	<200,000	<400,000	None	None	None
	200,000-<625,000	400,000-<1,600,000	228.6m	381m	381m
	625,000-<1,250,000	1,600,000-4,000,000	304.8m	571.5m	571.5m
	1,250,000 or more	4,000,000 or more	457.2m	762m	762m

DISTANCES TO WELLS

Type of Structure	**Public Well**		**Private Well**	
	Shallow	**Deep**	**Shallow**	**Deep**
Aerobic structure, anaerobic lagoon, earthen manure storage basin, egg wash-water storage structure and open feedlot runoff control basin	304.8m	121.92m	121.92m	121.92m
Formed manure structure, confinement building, open feedlot control basin	60.96m	30.48m	60.96m	30.48m

OTHER DISTANCES FOR ANIMAL FEEDING OPERATION STRUCTURES (regardless of animal weight capacity)

Surface intake, wellhead or cistern of agricultural drainage wells, known sinkholes or major water sources (Excluding farm ponds, privately owned lakes or when a secondary containment barrier is provided)	152.40m
Watercourses other than major water sources (Excluding farm ponds, privately owned lakes or when a secondary containment barrier is provided)	60.96m

Right-of-way of a thoroughfare maintained by a political subdivision (Excluding small feeding operations, dry manure storage or when permanent vegetation is provided)	30.48m

Appendix 3.13: Waste Treatment Technology in Scotland's Prevention of Environmental Pollution from Agricultural Activity

Mechanical Separation	Separation of solids and liquids through the use of screen or belt presses or centrifuges. Advantages to separation include allowing solids to compost once separated and then spreading without odour. Aeration of the slurry portion of the waste can then take place.
Anaerobic Digestion (AD)	AD involves storage in an insulated tank where the waste is mixed regularly and heated to 35 or 55°C. Recommended treatment periods are: 12-15 days for pig slurry, 20 days for cattle and poultry slurries.
Aerobic Treatment	Slurry can be aerated in tanks, or lagoons using compressed air or mechanical aerators. Aerobic treatments are short: 3-10 days to remove odours, reduce BOD, and manipulate nitrogen.
Slurry Acidification	Slurry Acidification is conducted to prevent ammonia emissions and therefore increase the amount of ammonia for plant growth. Slurry is acidified using nitrate, sulphuric or phosphoric acids. Not used too commonly because the benefits < cost.
Nitrification Inhibitors	Nitrification inhibitors are added to slurry to reduce nitrogen leaching when applied to land. These inhibitors keep the nitrogen in the form of ammonia instead of the more easily leachable nitrate. It is more economical to inject or immediately incorporate slurry into the soil when using this method, it makes the method more economical than when manure is surface applied especially since this method is weather sensitive.
Slurry Additives and Deodorants	These additives are short term solutions to odour problems. Additives include oxidizing agents, masking agents and biological digestive agents.
Composting	Composting is a natural aerobic process that stabilizes organic matter such as solid manure. The high temperatures that occur reduce the harmful organisms and there is no odour. The end result is a marketable product.

Note: These treatments are all recommended and the use of one treatment will depend on individual needs and farm operations.

Appendix 3.14: Summary of Land Application Regulations and Guidelines in Canada

	British Columbia		Alberta		Sask.		Manitoba		Que.	New Brunswick			Nova Scotia		PEI	NWT
	Agricultural Waste Control regulation	Drinking Water Protection Act	Agricultural Operations Practices Act	Water Act	Agricultural Operations Act	Livestock Operations Guidelines	Livestock Manure and Mortalities	Proposed NMS for Surface Water	Regulation Respecting Agricultural Operations	Livestock Operations Act Reg. 99-32	Wellfield Protected Areas	Manure Management Guidelines	Animal Manure and Use Guidelines	Siting and Management of Hog Farms	Guidelines for Manure Management	Guidelines for Agricultural Waste
Spreading:											[76]				[77]	
Require a plan?					YES [78]				YES, if >15ha	YES	YES					
MSD from:	[79]					[80]							[81]		[82]	
-watercourse			30m + [83]						30m			[84]				
-domestic			30m						30m			75m	30m	30m		

[76] Each Zone is restricted in the allowable amount of applied nutrients and fertilizers. (C>B>A).
[77] Spreading Agreements: Operators who do not have sufficient land base to effectively utilize the manure for growing crops should enter into written agreements with other land owners for the land application of manure for the purpose of growing crops. These should have a minimum duration of two years.
[78] Manure Spreading plans must include specific details that follow normally accepted agricultural practices that are laid out in the Livestock Operations Guidelines for Saskatchewan.
[79] No specific MSDs are given. Instead unfavorable conditions are listed including: on frozen land, in diverting winds, on areas having standing water, on saturated soils and in rates that exceed crop requirements.
80 See Appendix 3.18: Saskatchewan Manure Spreading Minimum Separation Distances.
[81] See Appendix 3.20: Minimum Recommended Separation Distances for Manure Application in the Guidelines for the Management and Use of Animal Manure in Nova Scotia.
82 See Appendix 3.21: Recommended Setback Distances for Spreading Manure in PEI.
83 See Appendix 3.17: Minimum Setback Distances in the Alberta Agricultural Operation Practices Act.
84 Manure should not be spread on sloping land to a watercourse without immediate incorporation or the provision of an appropriate buffer strip to prevent contamination of the watercourse. Liquid manure being spread on land within 300 meters of any watercourse must be spread at rates to ensure that all liquid is absorbed by the soil and no runoff occurs. *Manure should not be applied to land within 30 meters of the bank of any watercourse unless incorporated into the soil within one day. Manure should not be applied to land within 5 meters of the bank of a watercourse under any circumstances.*

	British Columbia		Alberta		Sask.		Manitoba		Que.	New Brunswick			Nova Scotia		PEI	NWT
	Agricultural Waste Control regulation	Drinking Water Protection Act	Agricultural Operations Practices Act	Water Act	Agricultural Operations Act	Livestock Operations Guidelines	Livestock Manure and Mortalities	Proposed NMS for Surface Water	Regulation Respecting Agricultural Operations	Livestock Operations Act Reg. 99-32	Wellfield Protected Areas	Manure Management Guidelines	Animal Manure and Use Guidelines	Siting and Management of Hog Farms	Guidelines for Manure Management	Guidelines for Agricultural Waste
water supply													clay/ loam, 60m sand/ gravel	clay/ loam, 60m sand/ gravel		
-ditches									1m							
Incorporation required?			YES, 48 hours			Yes, 24 hours						[85]	ASAP	ASAP		
Winter Application allowed?	No.					Not rec.	No[86]		No. Oct 1 – Mar 31			Not rec.	Not rec.	Not rec.	Not rec.	Not rec.
Soil Testing Required?			YES[87]													
Rates:																
Nitrogen rates:			YES				Lbs/ acre					YES	YES	YES	YES [88]	

85 When applied to fields located within 200m of a residence during the months of July and August, manure should be incorporated into the soil within 24 hours of application.

86 Manure spread on agricultural fields between November 10 and April 15 must adhere to specific setback distances, see Appendix 3.19. Small-scale livestock producers are exempt from the ban on winter spreading but must comply with mandatory setback distances.

87 Soil testing must be conducted every three years if the operator spreads more than 300 tonnes of manure annually.

88 The application rate of manure should not exceed the amount necessary to meet the crop nitrogen requirements. These guidelines present two methods of calculating application rates: 1) an estimated land base area using typical nutrient production rates, and 2) a detailed method using site specific manure and soil test results.

	British Columbia		Alberta		Sask.		Manitoba	
	Agricultural Waste Control regulation	Drinking Water Protection Act	Agricultural Operations Practices Act	Water Act	Agricultural Operations Act	Livestock Operations Guidelines	Livestock Manure and Mortalities	Proposed NMS for Surface Water
Phosphorous rates								
Non-normal Conditions								

	Que.	New Brunswick			Nova Scotia		PEI	NWT
	Regulation Respecting Agricultural Operations	Livestock Operations Act Reg. 99-32	Wellfield Protected Areas	Manure Management Guidelines	Animal Manure and Use Guidelines	Siting and Management of Hog Farms	Guidelines for Manure Management	Guidelines for Agricultural Waste
Phosphorous rates	Report				YES	YES		
Non-normal Conditions				89	90			

89 Where runoff is a risk, manure should not be spread if rain is expected within 24 hours.
90 It is recommended that farm operators avoid spreading manure on wet or saturated land.

Appendix 3.15: Summary of Land Application Regulations and Guidelines in the United States

	Washington		Iowa	Mo.	Wisconsin			Minn.	Mich.	Maine	Texas	Delaware	Nebraska	
	Dairy Nutrient Management Act	Manure Management Guidelines for Western Washington	Chapter 65: Animal Feeding Operations	Guide to Animal Feeding Operations	NR 151: Runoff Management	NR 243: Animal Feeding Operations	Guidelines for Applying Manure	Minnesota Rules: Chapter 7020: Feedlot Rules	GAAMPs for Manure Management and Utilization	Nutrient Management Act/ Regulations	Chapter 321 Subchapter B: CAFOs Rules	Nutrient Management Law Nutrient Management Program	Livestock waste Management Act	Title 130: Rules and Regulations
Spreading:							[91]			[92]	[93]			
MSD from:	[94]		[95]											
-watercourses		3.05-9.14m	60.96 m	[96]			Stream: 91.44m Lake: 304.8m	7.62m[97]	45.72m [98]		30.48m			9.14m [99]
-wells		30.48-60.96m	60.96 m.	91.44 m			15.24m	15.24m		30.48m				
-ditches		3.05m		15.24 m				7.6m						
-groundwater						25.4 cm								

[91] Please see Appendix 3.22 for Suitable Land for Manure Application in Wisconsin

[92] Nutrient Management Plans must be developed or approved by a certified Nutrient Management Planner. The NMPs are very site specific and spreading MSDs are determined based on topography, crop, location of water sources etc... The only minimum separation distance required on very operation is 30.48m from any domestic wells.

[93] Buffer strips must be used to separate watercourses from runoff carrying eroded soil and manure particles.

[94] Priority areas for land application of wastes should be on gentle slopes located as far as possible from waterways. When wastes are applied on more sloping land or land adjacent to waterways, other conservation practices should be installed to reduce the potential for off-site transport of wastes.

[95] Land application requirements are based on type of manure and method of application. Please see Appendix 3.23 for Required Separation Distances.

[96] 91.44m: losing streams,30.48m: permanent streams, 15.24: intermittent streams

[97] 7.6m unless it is defined as a Specially Protected Stream, in that case it is 30.48m

[98] Manures that are injected or surface applied with immediate incorporation can be closer than 45.72m as long as conservation practices are used to protect against runoff and erosion.

[99] When applied within 30.48m must construct buffer strips or incorporate.

	Washington		Iowa	Mo.	Wisconsin			Minn.	Mich.	Maine	Texas	Delaware	Nebraska	
	Dairy Nutrient Management Act	Manure Management Guidelines for Western Washington	Chapter 65: Animal Feeding Operations	Guide to Animal Feeding Operations	NR 151: Runoff Management	NR 243: Animal Feeding Operations	Guidelines for Applying Manure	Minnesota Rules: Chapter 7020: Feedlot Rules	GAAMPs for Manure Management and Utilization	Nutrient Management Act/ Regulations	Chapter 321 Subchapter B: CAFOs Rules	Nutrient Management Law Nutrient Management Program	Livestock waste Management Act	Title 130: Rules and Regulations
-bedrock						25.4 cm	25.4 cm[100]							
-property boundary			30.48 m	15.25 m.										
-public use area or dwelling				45.72 or 15.24 m[101]										
Incorporation required?	YES	YES	YES				YES, within 3 days	YES[102]	YES[103]			YES		
Winter Application allowed?	NO [104]	Only in certain areas[105].	Restrictions[106]			Restrictions [107]	Restrictions[108].	Not in special protected areas.	No[109].	No. Dec1st-Mar15th	NO	NO		NO

[100] Do not apply manure where there is less than 25.4cm of soil over bedrock. Where the soil is only 25.4cm to 50.8cm thick over bedrock do not apply more than 25 tons of manure and incorporate within 3 days. Do not apply manure to these soils when they are frozen.

[101] A 45.72m MSD is required if manure is land applied by an irrigation system. A 15.24m MSD is required if manure is land applied by tank wagon or solid spreader.

[102] On protected lands and on sloping lands both within 24 hours

[103] Incorporation of manure as soon as possible after application of manure, is highly recommended and is required when the slope of the land is 6% or greater.

[104] No application allowed if a potential risk of discharge to ground or surface waters exist.

[105] Never apply manure to bare corn fields (except whole solid and separated solids) from the beginning of September to late February.

[106] If application on frozen or snow-covered land is necessary it can only be applied on land that has a slope of less than or equal to 4%

[107] Manure may not be applied on frozen or snow-covered ground on fields with shallow soils that are 20 inches thick or less over fractured bedrock.

[108] When soils are frozen do not apply manure to fields with greater than 12% slope. If manure is applied to frozen fields with 6-12% slope, conservation measures must be in place.

	Washington		Iowa	Mo.	Wisconsin			Minn.	Mich.	Maine	Texas	Delaware	Nebraska	
	Dairy Nutrient Management Act	Manure Management Guidelines for Western Washington	Chapter 65: Animal Feeding Operations	Guide to Animal Feeding Operations	NR 151: Runoff Management	NR 243: Animal Feeding Operations	Guidelines for Applying Manure	Minnesota Rules: Chapter 7020: Feedlot Rules	GAAMPs for Manure Management and Utilization	Nutrient Management Act/ Regulations	Chapter 321 Subchapter B: CAFOs Rules	Nutrient Management Law Nutrient Management Program	Livestock waste Management Act	Title 130: Rules and Regulations
Application to saturated soils.	NO						NO.		NO.		NO	NO		NO. Can only apply on dewatering days.
Application if rain in forecast in the next 24 hrs.	NO	NO						Okay if incorporated			NO			
Soil Testing Required?	YES	YES every 2 yrs		YES			YES. Every 3-4 yrs.		YES	YES	YES	YES		YES
Rates:		Soil Infiltration rate					<25 tons manure/ acre/yr	[110]						
Nitrogen rates:			YES	YES			YES							YES. Agronomic rate for N.

[109] Application of manure to snow-covered or frozen soils should be avoided, but where necessary, solid manures should only be applied to areas where slopes are 6% or less and liquid manures should only be applied to soils where slopes are 3% or less. In either situation, provisions must be made to control runoff and erosion with soil and water conservation practices such vegetative buffer strips between surface waters and soils where manure is applied.
[110] Apply at a rate or frequency that will not allow soil phosphorous levels to increase over any six year period.

	Washington		Iowa	Mo.	Wisconsin			Minn.	Mich.	Maine	Texas	Delaware	Nebraska	
	Dairy Nutrient Management Act	Manure Management Guidelines for Western Washington	Chapter 65: Animal Feeding Operations	Guide to Animal Feeding Operations	NR 151: Runoff Management	NR 243: Animal Feeding Operations	Guidelines for Applying Manure	Minnesota Rules: Chapter 7020: Feedlot Rules	GAAMPs for Manure Management and Utilization	Nutrient Management Act/ Regulations	Chapter 321 Subchapter B: CAFOs Rules	Nutrient Management Law Nutrient Management Program	Livestock waste Management Act	Title 130: Rules and Regulations
Phosphorous rates							150lb/ acre		42 lb/acre					150ppm
Land Application of Stored Runoff Water									YES[111].					
Sloping fields		>slope= <man.						Must be incorporated						
Miscellany		Pasture applic[112].						Application method [113]	Infiltration Areas [114]					
Non-normal Conditions						[115]	[116]							

[111] Application rates should be determined based upon the ability of the soil to accept and store the water and the ability of plants growing in the application area to utilize nutrients. Land application should be done when the water can be beneficially used by a growing crop.

[112] For grassland or pastureland, apply manure at least 30 days before cutting to allow die-off of disease-causing bacteria and viruses. Manure applied within 7 days after each subsequent cutting reduces the likelihood of smothering grass and slowing re-growth.

[113] Manure application by a traveling gun, center pivot, or other irrigation equipment that allows liquid application of manure to travel more than 15.24m in the air is prohibited in special protection areas.

[114] An alternative to a storage pond is a structure for settling solids and an infiltration area (or vegetative filter) for handling lot runoff, milk parlor or milk house wastewater. The vegetated area may be either a long, grassed, slightly sloping channel, or a broad, flat area with little or no slope surrounded by a berm or dike. All outside surface water should be excluded from the infiltration area so that the only water applied is lot runoff and direct precipitation. Vegetation should be maintained and harvested at least once per year to prevent excessive nutrient buildup in the soil of the infiltration area.

[115] Discharge or leaching into a watercourse is not allowed unless the discharge occurs as a result of the 25-year, 24-hour rainfall event; or the discharge occurs as a result of a chronic rainfall event.

[116] On sands or loamy sands, apply manure only where a cover crop will be established or after October 31st when soil temperatures are probably less than 50°F.

Appendix 3.16: Summary of Land Application Regulations and Guidelines in Other Countries

	England	Finland	Netherlands	Scotland	
	Code of Good Agricultural Practice for the Production of Water	Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters.	Manure and Fertilizer Policy	PEPFAA Code of Practice	The Control of Pollution (Silage, Slurry, and Agricultural Fuel Oil) (Scotland) Regulations 2001
Spreading:				[117]	
MSD from:					
-watercourses	10m, must have a grassed buffer	10m, must be a grassed buffer		10m	
-wells	50m	30-100m, must be a riparian area[118]		50m	
-ditches	10m, grassed buffer required	10m, be a grassed buffer		10m	
-groundwater		Should be avoided			
-bedrock	>30cm				
Incorporation required?	YES[119]	YES[120]			
Winter Application allowed?	NO	NO. Oct 15-Apr15.[121]	NO. Even if not frozen or snow-covered, there is no application to sandy soils	NO. Not on snow-covered or frozen ground.	

[117] The PEPFAA code of Practice suggests that maps are created that site the risks and suitability of the land for spreading. Please see Appendix 3.24: Risk Categories for Land.

[118] The actual distance is based on slope of land, soil type and well structure.

[119] And must incorporate horizontally, not vertically, on sloping fields.

[120] Incorporate within 4 hrs in the spring and summer and 24 hrs in the fall.

	England	Finland	Netherlands	Scotland	
	Code of Good Agricultural Practice for the Production of Water	Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters.	Manure and Fertilizer Policy	PEPFAA Code of Practice	The Control of Pollution (Silage, Slurry, and Agricultural Fuel Oil) (Scotland) Regulations 2001
			between Sept 1^{st} and Feb 1^{st}.		
Vegetated Buffer strips	Around watercourses and ditches (10m)	All MSDs must be vegetated.		Around watercourses of 10m (suggested width)	
Application to saturated soils.	NO[122]	NO[123]		NO	
Application if rain in forecast in the next 24 hrs.				NO	
Soil Testing Required?		Yes, every 5 years.		Yes, every 4 years.	
Rates:	$25m^3$/ha			Never >$50m^3$/ha[124]	
Nitrogen rates:	250kg/ha/yr	170kg/ha/yr			
Phosphorous rates					
Required time between applications		[125]		3 weeks.	
Land Application of Stored Runoff Water					

[121] If ground is not frozen, manure can be applied until November 15^{th} and can be applied starting April 1^{st} if the land is sufficiently dry.

[122] Spreading is prohibited on saturated soils but also in the opposite case when soil is cracked down to field drains or backfill, or when the field has been sub-soiled in the last 12 months.

[123] Cannot also not apply manure to areas that are repeatedly flooded in the spring.

[124] Please See Appendix 3.25: Surface Application Rates in Optimum Conditions

[125] If crops require more than 170kg/ha/yr, then the application must be split in two with two weeks in between.

	England	Finland	Netherlands	Scotland	
	Code of Good Agricultural Practice for the Production of Water	Decree on the Restriction of Discharge of Nitrates from Agriculture into Waters.	Manure and Fertilizer Policy	PEPFAA Code of Practice	The Control of Pollution (Silage, Slurry, and Agricultural Fuel Oil) (Scotland) Regulations 2001
Sloping fields	[126]	Cannot apply manure to fields with slopes of >10%.	Cannot apply manure to fields with slopes of >7%.	No application of land with a slope >11°. [127]	
Miscellany		Fall rates of application[128]		No spreading when fields have been pipe or mole drained, or sub-soiled over existing drains within the last 12 months.	

[126] Spreading is prohibited when fields next to a watercourse, spring or borehole where the surface is severely compacted or water logged or have a steep slope and the soil is at field capacity, or the field has a moderate slope but has only a moderately permeable soil.
[127] This is very site dependent. Application is allowed on land with up to a 15° slope but only if the soil, land, and climatic factors are of acceptable risk and no risk to local water quality.
[128] There are maximum amounts of manure that can be applied in the autumn, these include: 30 tonnes/ha of solid manure, 20 tonnes/ha of cow slurry, 15 tonnes/ha of pig slurry, or 10 tonnes/ha of poultry or fur animal manure.

Appendix 3.17: MSDs for the Application of Manure in the Alberta Agricultural Operations Practices Act.

Table One: Minimum Setback Distances for Application of Manure on Frozen or Snow Covered Land.

Mean Slope	Required Setback Distance from Common Body of Water
<4%	30m
4%<6%	60m
6%<12%	90m
>12%	No application allowed

Table Two: Minimum Setback Distance for Application of Manure on Forage or Direct Seeded Crop.

Mean Slope	Required Setback Distance from Common Body of Water
<4%	30m
4%<6%	60m
6%<12%	90m
>12%	No application allowed

Appendix 3.18: MSDs for the Application of Manure in Saskatchewan.

	Injected	Incorporated within 24 hrs	No Incorporation
For Public			
1-1000 people	200	400	800
1000-5000 people	400	800	1200
>5001 people	400	800	1600
For Water Protection			
Domestic groundwater supply on land not controlled by the operator to which water runoff will not flow.	100	100	100
Watercourse or body of water not contained on land controlled by the operator to which the runoff water will not flow.	30	30	30
Watercourse or body of water not contained on land controlled by the operator to which the runoff water will flow.	30	150	300

Appendix 3.19: Setback Requirements for Winter Application of Livestock Manure in Manitoba

Where livestock manure spreading on land between November 10 of one year and April 15 of the following year is allowed under this regulation, the following minimum setback distance requirements apply from any surface watercourse, sinkhole, spring or well.

Slope of the land:	Distance
any	10m from any property boundary
<4%	150m
4%-6%	300m
>6%	450m

Appendix 3.20: MSDs for the Application of Manure in Nova Scotia

Non-Compatible Land Use	**Separation Distance (metre)**	
	Clay loam and Loam Soils	Sand and Gravel Soils
Dug or Drilled Wells	30	60
Water Courses		
Slope Towards Water Course		
<2%	20	50
2-5%	50	75
5-10%	100	100
>10%	Not Recommended	Not Recomended

Appendix 3.21: Recommended MSDs for the Application of Manure in P.E.I.

	Surface Applied	
Distance From:	**No tillage**	**Tillage within 48 hours after spreading**
Active recreational area, restaurant, motel (except June 20 to September 8)	Spread to property line	Spread to property line
Residences and businesses	Spread to property line	Spread to property line
Active recreational area, restaurant, motel (June 20 to September 8)	180m	90m
Flowing watercourse where slope of land adjacent to the watercourse is less than 5%	30m	10m
Flowing watercourse where slope of land adjacent to the watercourse is greater than 5%	60m	30m

Appendix 3.22: Suitable Land for Manure Application in Wisconsin

Areas Suitable for Spreading in Winter (when the ground is frozen):
• Fields greater than 91.44m from streams or 304.8m from lakes. • Fields with more than 50.8cm of soil over bedrock. • Fields with less than 6% slopes. • Fields with 6-12% slopes if conservation practices are in place.
Areas Suitable for Spreading in the Fall (before October 31):
• Fields with medium to fine-textured soils (not sands or loamy sands). • Fields with more than 50.8 cm of soil over bedrock.
Areas that are not Suitable for Spreading unless the Manure will be Worked into the Soil within 3 days:
• Fields within 91.44m of streams or 304.8m of lakes. • Fields with soil that is only 25.4-50.8cm thick over bedrock.
Areas that are never Suitable for Spreading Manure:
• Land that is wet or frequently flooded (within the 10 year flood plain). • Grassed waterways, terrace channels, open surface drains or other areas where water flow may concentrate. • Land with less than 25.4cm of soil over bedrock.

Appendix 3.23: Required Separation Distances for Protected Areas by Type of Manure and Method of Manure Application in Iowa.

Table One: Required Separation Distances (m) for Protected Areas by Type of Manure and Method of Manure Application, excluding Irrigation.

Protected Areas	Dry Manure		Liquid Manure (except irrigated)		
	Surface Application		Direct Injected	Surface Application	
	Incorporation within 24 hours	After 24 hours or no incorporation		Incorporation within 24 hours	After 24 hours or no incorporation
Buildings or Public Use Areas: residence, business, church, school, park	0	0	0	0	228.6a
Designated Areas: Sinkhole, abandoned well, drinking well, lake or farm pond, ag drainage well, surface tile inlet	0	60.96b	0	0	60.96b

a: This separation distance does not apply if the following exist:

- A written waiver is issued by titleholder of the land benefiting from the waiver
- Manure comes from a small animal feeding operation (SAFO)
- Manure is applied by low pressure spray irrigation equipment, (a 250-ft separation distance applies)

b: Or if a 15.25m buffer is established, manure can be applied up to the buffer.

Appendix 3.23: Required Separation Distances for Protected Areas by Type of Manure and Method of Manure Application in Iowa.

Table Two: Required Separation Distances (m) for Land Application of Irrigated Liquid Manure.

Protected Areas	Irrigated Liquid Manure	
	Low Pressure (<25 psi)	High Pressure (>25 psi)
Property Boundary Line	30.48m	30.48m
Buildings or Public Use Areas: residence, business, church, school, public use area	76.2m	228.6m
Designated Areas (except ag drainage well intakes): sinkhole, abandoned well, cistern, drinking water well, lake or farm pond, privately owned lake	60.96m[a]	60.96m[a]
Designated Areas: unplugged ag drainage well, ag drainage well surface tile inlet	No Irrigation Allowed	No Irrigation Allowed
Agricultural Drainage Well Area (watershed)	No Irrigation Allowed	No Irrigation Allowed

a: Or if a 15.24m buffer is established, manure can be applied up to the buffer.

Appendix 3.24: Risk Categories of Land in Scotland's Prevention of Environmental Pollution from Agricultural Activity.

High Risk Areas	**Moderate Risk Areas**	**Low Risk Areas**
• Slopes with a gradient of 8-11°	• Slopes with a gradient of 4-7°	• Slopes with a gradient of 0-3°
• Areas with a risk of flooding more often than one in five years	• Land sloping toward watercourses or water supplies	• Land with no artificial drainage
• Sandy or shallow soils (<30cm) over gravel or fissured rock	• Imperfectly drained or saturated soil	
• Fields with drainage installed in the previous 12 months		
• Poorly drained, waterlogged, or severely compacted land.		

Appendix 3.25: Surface Application Rates in Optimum Conditions in Scotland's Prevention of Environmental Pollution from Agricultural Activity.

Material	Maximum Application Rate	Normal Application Rate
Slurry	$50m^3$/ha	20-30 m^3/ha
Injected Slurry	140 m^3/ha	
Manure	50 tonnes/ha	30-50 tonnes/ha
Poultry Manure	5-15 tonnes/ha	5-15 tonnes/ha
Contaminated water	50 m^3/ha	25-30 m^3/ha

Appendix 3.26: Required Components of Nutrient Management Strategies and Nutrient Management Plans in the Ontario Nutrient Management Act (2002)

	Content	Required in a Strategy	Required in a Plan
Operation Information	Description of the Operation	Y	Y
	Agreements	Y	Y
For Farm Units Only	Farm Unit Sketch declaration Form	Y	Y
	Farm Unit Sketch	Y	Y
	Minimum Separation Distance II	Y	Y
Inventory and Description of Prescribed Manaterials	List of Prescribed Materials (generated and received)	Y	Y
	Nutrient Analysis	Y	Y
Destination and Storage	Destinations	Y	Y
	Storage Facilities	Y	Y
	Contingency Plan	Y	Y
	Certification Form	Y	Y
Field Information	Field Properties	N	Y
	Field Sketches	N	Y
	Soil Samples and Analysis	N	Y
Crop Information	Crop Rotation and Yields	N	Y
	Tillage Practices	N	Y
Nutrient Application Information	Commercial Fertilizer Application	N	Y
	Application of Prescribed Materials	N	Y
	Agronomic and Crop Removal Balance for Nitrogen	N	Y
	Nitrogen Index	N	Y
	Application limits for Phosphorous	N	Y
	Phosphorous Index	N	Y
	Common Land Application Setbacks/Limits	N	Y
	Demonstration of Adequate Landbase	N	Y

Source: Nutrient Management Protocols for Ontario Regulations Made under the Nutrient Management Act, 2002.

Appendix 3.27: Application to Land when Bedrock is Present in the Ontario Nutrient Management Act (2002)

Depth of soil over bedrock	Treated liquid materials, or runoff liquid materials other than untreated liquid manure	Solid Manure	Untreated Liquid Manure
<15cm	No application allowed	No application allowed	No application allowed
15-30cm	Application allowed under the following conditions: 1. Land tilled within 7 days prior to application, and 2. Max. application rate $<40m^3/ha$	Application allowed under the following conditions: 1. Max. application rate <45t/ha	No application allowed
30-6-cm	Either, 1. Max. application rate $<40m^3/ha$, or 2. if land tilled within 7 days before application, max. application rate $<75\ m^3/ha$	Maximum application rate < 85t/ha	Application allowed under the following conditions: 1. Land tilled within 7 days prior to application 2. Max. application rate $<40\ m^3/ha$
60cm-1.5m	No restriction on application.	No restriction on application.	Either, 1. Max. application rate $<40\ m^3/ha$, or 2. if land tilled within 7 days prior to application, max. application $< 75\ m^3/ha$

Appendix 3.28: Rates of Application in the Ontario NMA (2002)

Table One: Runoff Potential of the Field

Soil Hydrologic Group	Runoff Potential for Table Two (or application prohibition) Maximum sustained field slope within 150m of watercourse			
	Less than 3%	3 to 6%	6-9%	9% or more
A Rapid	Very Low	Very Low	Low	High
B Moderate	Very Low	Low	Moderate	High
C Slow	Low	Moderate	High	No application allowed
D Very Slow	Moderate	High	High	No application allowed

Table Two: Single Application Liquid Prescribed Material Loading Limit

Runoff Potential (from Table One)	Maximum rate if applied to surface	Maximum rate if injected, incorporated[a], or pretilled[b]
High	50 m^3/ha	75 m^3/ha
Moderate	75 m^3/ha	100 m^3/ha
Low	100 m^3/ha	130 m^3/ha
Very Low	130 m^3/ha	150 m^3/ha

a: Incorporation must occur within 24 hours after manure application.

b: The land on which the nutrient is applied must have been tilled within the period of 7 days before application.

Appendix 3.29: Odour Categories in the Ontario Nutrient Management Act (2002)

01 (Low Odour) Materials that have an odour which is less intensive than solid dairy cattle manure.	Agricultural lime
	Bark
	Cement kiln dust
	Chemical fertilizers
	Leaves
	Lime mud
	Magnesium residuals
	Matured fertilizing residuals compost
	Matured manure compost
	Paper biosolids with Carbon/Nitrogen >=70
	Wood Ash
	Wood Chips
02 (Moderate Odour) Materials that have an odour that is similar to solid dairy cattle manure.	Acid treated paper biosolids
	Beef cattle manure
	Solid dairy cattle manure
	Immature manure compost
03 (High Odour) Material that is more intense than diary cattle manure but equal to or less than liquid hog manure.	Abattoir waste and washwater
	Grass clippings
	Liquid beef cattle manure
	Liquid dairy cattle manure
	Liquid laying hen manure
	Liquid milk calf manure
	Liquid hog manure
	Milkhouse wastewater
	Milk wastes
	Sewage biosolids
	Non-acid treated paper biosolids with Carbon/Nitrogen<70
	Potato wastes
	Whey
	Paper biosolids that have been stored for > 30 days before application

Appendix 4.1: Survival of Pathogens in Manure

Pathogen Type	Manure Type	Manure Management Techniques	Climate	Log Reduction or T_{90}	Viability in Days	Reference:
E. coli O157:H7 (1.7 x 10^8 cfu/g)	Cattle	Manure held in 100ml closed plastic containers	1. 10°C held inside 2. Outside mid-Jan to mid-April (-6.5-19°C)	No sig. difference between the two containers. 1.7 x 10^8 cfu/g (at 0d) to 3.7 x 10^2 cfu/g (at 99d)		Bolton et al. 1999
Cryptosporidium (10^6 oocysts/g)	Calf	Samples were strained and stored in glass containers in the dark.	4°C		14% (1.4 x 10^5/g) viable after 259d; 10% (10^5/g) viable after 410d	Jenkins et al. 1997
Cryptosporidium parvum (2.8 x 10^7 oocysts/container)	Cattle	Semi-permeable container put into 25L of cow manure stored in a plastic bucket in a dark outside storage area.	Kept as close to 4°C as possible.		After 176 days, 39.6% (10^7 oocysts) of the oocysts were viable.	Robertson et al. 1992.
E. coli O157:H7 (10^3 to 10^4 CFU/g)	Fresh Cattle manure	Plastic bags used to incubate manure to desired temperature.	4°C 20°C 37°C	13.82d 17.56d 6.25d		Himathongkham, 1999
Salmonella typhumurium (10^3 to 10^4 CFU/g)	Fresh Cattle manure	Plastic bags used to incubate manure to desired temperature.	4°C 20°C 37°C	16.52d 17.03d 5.05d		Himathongkham, 1999
E. coli O157:H7 (10^3 to 10^4 CFU/g)	Fresh Poultry manure	Plastic bags used to incubate manure to desired temperature.	4°C 20°C 37°C	15.35d 1.45d 0.59d		Himathongkham, 1999
Salmonella typhimurium (10^3 to 10^4 CFU/g)	Fresh Poultry manure	Plastic bags used to incubate manure to desired temperature.	4°C 20°C 37°C	10.1d 1.59d 0.61d		Himathongkham, 1999
E. coli O157:H7 10^5 cfu/g (high)	Cattle	Closed plastic bags	5°C 15°C		56d 126d	Fukushima et al. 1999

Pathogen Type	Manure Type	Manure Management Techniques	Climate	Log Reduction or T_{90}	Viability in Days	Reference:
			25°C[129]		56d	
E. coli O157:H7 10^3 cfu/g (med.)	Cattle	Closed plastic bags	5°C		56d	Fukushima et al. 1999
			15°C		56d	
			25°C[130]		56d	
E. coli O157:H7 10^1 cfu/g (low)	Cattle	Closed plastic bags	5°C		42d	Fukushima et al. 1999
			15°C		56d	
			25°C[131]		56d	
E. coli O157:H7 (10^3 CFU/g)	Cattle	Opened stomacher bags	5°C		63d	Wang et al. 1996
			22°C[132]		49d	
			37°C		21d	
E. coli O157:H7 (10^5 CFU/g)	Cattle	Opened stomacher bags	5°C		70d	Wang et al. 1996
			22°C[133]		56d	
			37°C		21d	
E. coli O157:H7 (10^6/g)	Cattle				50d	Maule, 2000
Cryptosporidium 10^7 oocysts/g	Calf		-4°C		>84d	Olsen et al. 1999
			4°C		56d	
			25°C		28d	
Giardia 10^5 oocysts/g	Calf		-4°C		<7d	Olsen et al. 1999
			4°C		7d	
			25°C		7d	

[129] At this temperature there was initial growth of *E. coli* O157:H7 before the population decreased.
[130] At this temperature there was initial growth of *E. coli* O157:H7 before the population decreased.
[131] At this temperature there was initial growth of *E. coli* O157:H7 before the population decreased.
[132] At temperatures of 22°C and 37°C there was initial growth of *E. coli* O157:H7 before the population decreased.
[133] At temperatures of 22°C and 37°C there was initial growth of *E. coli* O157:H7 before the population decreased.

Appendix 4.2: Survival of Pathogens in Slurry

Pathogen	Manure Type	Manure Management Techniques	Climate	Log Reduction or T_{90}	Viability in Days	Reference:
Salmonella typhimurium					110days	Stewart, 1961
Escherichia coli (3.0 x 10^6 units/mL)	Cattle slurry (Dry matter 2%)	Cleaned slurry tank once per month..	Anaerobic storage, mid-October – end of February.		3.0 x 10^2 units/mL after 63d	Burrows and Rankin, 1970
Escherichia coli (1.6 x 10^6 units/mL)	Cattle slurry (Dry matter 4.5%)	Cleaned slurry tank three times a week, therefore always fresh slurry.	Anaerobic storage, mid-October – end of February.		8.9 x 10^2 units/mL after 77d	Burrows and Rankin, 1970
Salmonella typhimurium (6.0 x 10^6 units/mL)	Cattle slurry (Dry matter 2%)	Cleaned slurry tank once per month.	Anaerobic storage, mid-October – end of February.		2.2 x 10^3 units/mL after 63d	Burrows and Rankin, 1970
Salmonella typhimurium (2.0 x 10^6 units/mL)	Cattle slurry (Dry matter 4.5%)	Cleaned slurry tank three times a week, therefore always fresh slurry.	Anaerobic storage, mid-October – end of February.		6.0 x 10^3 units/mL after 63d	Burrows and Rankin, 1970
Salmonella typhimurium (8.8 x 10^6/ml)	Cattle slurry	7 gallon tanks covered with lids and left outdoors from mid-January to mid-April (England)	Outdoors mid-January to mid-April in England.		10^2 at 77 days	Rankin and Taylor, 1969[134]
Samonella Dublin (5.5 x 10^6/ml)	Cattle slurry	7 gallon tanks covered with lids and left outdoors from mid-January to mid-April (England)	Outdoors mid-January to mid-April in England.		10^2 at 77 days	Rankin and Taylor, 1969
Escherichia coli (6.6 x 10^6/ml)	Cattle slurry	7 gallon tanks covered with lids and left outdoors from mid-January to mid-April (England)	Outdoors mid-January to mid-April in England.		10^3 at 77 days	Rankin and Taylor, 1969

[134] This study concluded that although numbers dropped significantly at 11 weeks, after two weeks contamination of the slurry, at a time when the tank would normally be emptied, the bacterial count was still very high.

Pathogen	Manure Type	Manure Management Techniques	Climate	Log Reduction or T_{90}	Viability in Days	Reference:
E. coli O157:H7 (10^6/ml)	Cattle slurry				Undetectable after 10d	Maule, 2000
Salmonella dublin (10^6/ml)	Cattle Slurry	8 replicate 400ml amounts each seeded with 10^6/ml *S. dublin.*	5°C		132d	Jones, 1976
			10°C		132d	
			20°C		57d	
			30°C		13d	
E. coli O157:H7 (10^3 to 10^4 CFU/ml)	Fresh Cow slurry	Plastic bags used to incubate slurry to desired temperature.	4°C	21.51d		Himathongkham, 1999
			20°C	14.75d		
			37°C	3.18d		
Salmonella typhimurium (10^3 to 10^4 CFU/ml)	Fresh Cow slurry	Plastic bags used to incubate slurry to desired temperature.	4°C	16.42d		Himathongkham, 1999
			20°C	12.69d		
			37°C	2.37d		
E. coli O157:H7 (10^3 to 10^4 CFU/ml)	Fresh Poultry Slurry	Plastic bags used to incubate slurry to desired temperature.	4°C	156.25d		Himathongkham, 2000
			20°C	6.91d		
			37°C	1.90d		
Salmonella typhimurium (10^3 to 10^4 CFU/ml)	Fresh Poultry Slurry	Plastic bags used to incubate slurry to desired temperature.	4°C	44.64d		Himathongkham, 2000
			20°C	6.60d		
			37°C	1.75d		

Appendix 4.3 Survival of Pathogens in Soil

Escherichia coli

Pathogen	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability or Viability in Days	Log Reduction	Reference:
E. coli O157:H7 (10^8 cfu/g)	Cattle	Grassland		Mid-Jan to mid-April (-6.5-19°C)		4.0-5.0 log10 cfu/g reduction within 50 days but still detectable after 99 days[135]	Bolton et al. 1999
E. coli O157:H7 (10^6 *E. coli*/g)	Tracer Bacterium	Plastic lined bins	Sandy	December to May in Scotland.	10^1/g at 56 days		Fenlon et al. 2000
			Loam		10^1/g at 175 days		
			Clay loam		10^1/g at 175 days		
E. coli O157:H7 (5.3×10^4 cfu/g)	Dairy cattle slurry	2 barley fields and 2 pastures	Clay loam	Mid-March in Scotland		1% (5.3×10^2) left in soil on day 29[136].	Fenlon et al. 2000
E. coli O157:H7 (10 orgs/g)	Sheep	Grassland	Loamy sand	Higher than average rainfall	Up to 105d[137]		Ogden et al. 2002
E. coli 10^{12}-10^{13} CFU/g	Tracer bacterium	Tapered plastic pots	Sandy loam: pH 6.8-8.3	5°C (15% moist.)	285d[138]		Sjogren, R. 1994
				10°C (15% moist.)	348d		
				20°C (15% moist.)	171d		
				37°C (15% moist.)	21d		
E. coli 10^{12}-10^{13} CFU/g	Tracer bacterium	Tapered plastic pots	Sandy loam: pH 5.5-7.2	5°C (15% moist.)	189d		Sjogren, R. 1994
				10°C (15% moist.)	291d		
				20°C (15% moist.)	159d		
				37°C (15% moist.)	24d		
E. coli 10^{12}-10^{13} CFU/g	Tracer bacterium	Tapered plastic pots	Sandy loam: pH 6.8-8.3	5°C (saturated)	408d[139]		Sjogren, R. 1994
				10°C (saturated)	393d		
				20°C (saturated)	174d		
				37°C (saturated)	24d		
E. coli 10^{12}-10^{13} CFU/g	Tracer bacterium	Tapered plastic pots	Sandy loam: pH	5°C (saturated)	351d		Sjogren, R. 1994
				10°C (saturated)	282d		

[135] The results demonstrated the presence of *E. coli* O157:H7 in 70% of soil samples after 85 days and in 20% of soil samples after 99 days. This study shows that survival strongly depends on soil type.

[136] Because of rain events most *E. coli* was found in runoff and drainage.

[137] The authors note that there is a possibility that the *E. coli* was deposited in sheep feces up to 14 weeks previous to the study and therefore the estimate of 15 weeks survival may be low.

[138] Calculated using an exponential regression analysis to zero counts.

[139] The results of the two experiments with the varying soil pH show that survival is greater in a soil that is more neutral.

Pathogen	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability or Viability in Days	Log Reduction	Reference:
			5.5-7.2	20°C (saturated)	159d		
				37°C (saturated)	27d		
E. coli ($9 x 10^5$ CFU/ml)	Liquid Manure	Plastic tubes	Garden Soil	8°C	108d[140]		Tamasi, 1981
				20°C	54d		
E. coli ($9 x 10^5$ CFU/ml)	Liquid Manure	Plastic tubes	Sand	8°C	131d		Tamasi, 1981
				20°C	102d		
E. coli O128		Rye-grass pasture			41d[141]		Sjogren, 1995
Fecal Coliforms ($1.3 x 10^5$/g) *indicator organisms	Manure Slurry	Bottled soil incubated at 22°C in the dark	Fine Sand	14.39 m^3/ha	$5.0 x 10^1$ after 56d		Dazzo et al. 1973[142]
				28.83 m^3/ha	$1.6 x 10^2$ after 56d		
				57.67 m^3/ha	$3.2 x 10^2$ after 56d		
E. coli O157:H7 (10^8/g)		Soil cores containing rooted grass			10^7/g after 130d		Maule, 2000
E. coli O157 :H7 (1 part manure to 10 parts soil)	Cow Manure	Polyethylene plastic box with lid	Sandy loam	5°C	42d		Jiang et al. 2001[143]
				15°C	34d		
				21°C	103d		
E. coli O157 :H7 (1 part manure to 25 parts soil)	Cow Manure	Polyethylene plastic box with lid	Sandy loam	5°C	42d		Jiang et al. 2001
				15°C	152d		
				21°C	193d		
E. coli O157 :H7 (1 part manure to 50 parts soil)	Cow Manure	Polyethylene plastic box with lid	Sandy loam	5°C	56d		Jiang et al. 2001
				15°C	109d		
				21°C	174d		
E. coli O157 :H7 (1 part manure to 100 parts	Cow Manure	Polyethylene plastic box with lid	Sandy loam	5°C	49d		Jiang et al. 2001
				15°C	109d		
				21°C	131d		

[140] These observations were taken at a depth of 10cm.
[141] The *E. coli* also penetrated into the soil and was present in the plots for 13 years.
[142] Concluded that increasing the organic content of the soil caused an increase in the longevity of coliforms in the soil.
[143] This study compared the survival of *E. coli* O157:H7 in autoclaved and unautoclaved soil. Autoclaved soil was used as a control to minimize the influence of indigenous soil microorganisms on the survival and growth of *E. coli* O157:H7. Microorganisms naturally occurring in soil had an effect on survival as all survival times of autoclaved soil were greater than the survival times in unautoclaved soil. All of the data in this matrix represents the results of the unautoclaved soils.

Cryptosporidium parvum

Pathogen	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability in Days	Log Reduction	Reference:
Cryptosporidium parvum (5x10^9 oocysts)	Cow slurry (420 cm^3)	Tilting table apparatus at a 7.5% slope.	Clay loam soil with grass intact.	Simulated heavy rainfall (3.4L at a time)	70d[144]		Mawdsley et al. 1996b
Cryptosporidium parvum 10^7 oocysts/mL	Oocyst suspension	2.0g normal soil in a 15mL tube.	14.6% sand, 58.2% silt, and 27.7% clay	-4°C	70d		Olson et al. 1999
				4°C	56d		
				25°C	28d		
Cryptosporidium parvum 10^7 oocysts/mL	Oocyst suspension	2.0g autoclaved soil in a 15mL tube.	14.6% sand, 58.2% silt, and 27.7% clay	-4°C	>84d		Olson et al. 1999
				4°C	>84d		
				25°C	42d		

Giardia

Pathogen Type	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability in Days	Log Reduction	Reference:
Giardia 10^5 oocysts/mL	Cyst suspension	2.0g normal soil in a 15mL tube	14.6% sand, 58.2% silt, and 27.7% clay	-4°C	<7[145]		Olson et al. 1999
				4°C	49		
				25°C	7		
Giardia 10^5 oocysts/mL	Cyst suspension	2.0g autoclaved soil a 15mL tube.	14.6% sand, 58.2% silt, and 27.7% clay	-4°C	<7		Olson et al. 1999
				4°C	42		
				25°C	7		

Salmonella

Pathogen	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability or Viability in Days	Log Reduction	Reference:
Salmonella Enteriditis	Manure Slurry	Bottled soil incubated at 22°C	Fine Sand	14.39 m^3/ha	3.9 x 10^1 after 56d		Dazzo et al. 1973[146]

[144] The majority of oocysts were found in the top 6cm of the soil. The experiments were terminated at 70 days, therefore survival may have been extended.
[145] Autoclaved soil had no effect on cyst degradation or viability.

(7.8×10^5/g)		in the dark		28.83 m^3/ha	3.7×10^2 after 56d		
				57.67 m^3/ha	5.0×10^2 after 56d		
Salmonella Typhimurium (1.3×10^7/25cm^2 pasture)	Salmonella suspension	75cm x 75cm Exposed field plot[147]	Ryegrass-clover pasture	Summer	5 at 42d[148]		Tannock and Smith, 1971
				Winter	4 at 42d		
Salmonella Typhimurium (2.9×10^7/25cm^2 pasture)	Salmonella suspension	75cm x 75cm Shaded field plot[149]	Ryegrass-clover pasture	Summer	2 at 70d		Tannock and Smith, 1971
				Winter	8 at 28d		
Salmonella (10^5 CFU/ml)	Liquid Manure	Plastic tubes	Garden Soil	8°C	96d[150]		Tamasi, 1981
				20°C	54d		
Salmonella (10^5 CFU/ml)	Liquid Manure	Plastic tubes	Sand	8°C	131d		Tamasi, 1981
				20°C	131d		
Salmonella Typhimurium (1.5×10^4/g)	Fresh beef slurry	24ml glass containers; 0.5 atm moisture tension	Houston Black clay soil	5°C	1.5×10^1/g soil at 63 days		Zibilske and Weaver, 1978
				22°C	7.0×10^1/g soil at 42 days		
				39°C	5.0×10^2/g soil at 3 days		
Salmonella Typhimurium (1.5×10^4/g)	Fresh beef slurry	24ml glass containers; 0.5 atm moisture tension	Amarillo fine sandy loam	5°C	1.8×10^2/g soil at 3 days		Zibilske and Weaver, 1978
				22°C	4.4×10^1/g soil at 42 days		
				39°C	3.9×10^1/g soil at 21 days		

[146] Concluded that increasing the organic content of the soil caused an increase in the longevity of the *Salmonella* in soil.
[147] Each plot was sprayed evenly with a spray gun so that each plot received approximately 1×10^8 *Salmonellae* per 25cm^2.
[148] Mean count of *Salmonella* per 25cm^2 of pasture
[149] Each plot was sprayed evenly with a spray gun so that each plot received approximately 1×10^8 *Salmonellae* per 25cm^2.
[150] These observations were taken at a depth of 10cm.

Appendix 4.4: Survival of Pathogens in Water

Escherichia coli

Pathogen	Water Type	Experiment Characteristics	Climate	Viability in Days	T90 or Log Reduction	Reference:
E. coli O157:H7 (10^3 CFU/ml)	Autoclaved municipal	Inoculated water and held in sterile bottles.	8°C	10^2 at 91 days		Wang and Doyle, 1998
			15°C	6.3 x 10^1 at 91 days		
			25°C	>91 days (entered a VBNC state at 77 days)		
E. coli O157:H7 (10^3 CFU/ml)	Reservoir	Inoculated water and held in sterile bottles.	8°C	4.0 x 10^1 at 91 days		Wang and Doyle, 1998
			15°C	>91 days (entered a VBNC state at 77 days)		
			25°C	77 days (entered a VBNC state at 49 days)		
E. coli O157:H7 (10^3 CFU/ml)	Lake Jackson	Inoculated water and held in sterile bottles.	8°C	3.1 x 10^1 at 91 days		Wang and Doyle, 1998
			15°C	91 days (entered a VBNC state at 56 days)		
			25°C	70 days (entered a VBNC state at 35 days)		
E. coli O157:H7 (10^3 CFU/ml)	Lake Herrick (higher total aerobic bacteria counts than L. Jackson)	Inoculated water and held in sterile bottles.	8°C	10^1 at 91 days		Wang and Doyle, 1998
			15°C	49 days (entered a VBNC state at 14 days)		
			25°C	49 days (entered a VBNC state at 21 days)		
E. coli (10^6 to 10^8 organisms/ml)	Groundwater	20ml McFeters survival chambers were used to house the groundwater taken from a domestic well.	Water temperature ranged from 3-15°C.		Decay rate of 0.32/day.	Keswick et al. 1982
E. coli	Groundwater	100ml glass flasks containing groundwater were incubated in the dark for 15 days.	22°C		6.2d T90	Bitton et al. 1983

Pathogen	Water Type	Experiment Characteristics	Climate	Viability in Days	T90 or Log Reduction	Reference:
E. coli O157:H7 ($5x10^3$ org/ml)	Cattle drinking water (well water pumped to a cattle watering area and chlorinated)	1L of water was placed into sterile 2-L glass bottles with closures and incubated in the dark. The groundwater was dechlorinated using UV. 1g of manure was added/L of water[151].	5°C	$8x10^1$ org/ml at day 16		Rice and Johnson, 2000
			15°C	$1.7x10^1$ org/ml at day 16		
E. coli O157:H7 ($1.7x10^2$ org/ml)	Cattle drinking water from a surface source	1L of water was placed into a sterile 2l glass bottle with closures and incubated in the dark. 1g of manure was added/L of water[1].	5°C	<0.002 org/ml at day 16		Rice and Johnson, 2000
			15°C	<0.002 org/ml at day 16		
E. coli (10^4 cfu/ml)	Autoclaved river water	Microcosm Erlemeyers were placed at 5 or 15°C in the dark at 100rpm.	5°C		$0.010log^{10}$/day	Medema et al. 1997
			15°C		$-0.008log^{10}$/day	
E. coli (10^2-10^4 cfu/ml)	Natural river water		5°C		$0.102log^{10}$/day	Medema et al. 1997
			15°C		$0.202log^{10}$/day (0-14days) and $0.049log^{10}$/day (14-42 days)[152]	
E. coli	Irrigation stream water	Suspensions within membrane diffusion chambers were immersed in large vessels of stream water and changed daily	6°C		2.2d[153]	Terzieva and McFeters, 1991
			16°C		1.3d	

[151] In a natural setting, cattle feces would be the source of the *E. coli* O157:H7, therefore manure was added to mimic a fecal contamination event.
[152] A rapid initial die-off in the first 2 weeks, followed by a slower die-off in the subsequent weeks.
[153] This value is the arithmetic mean of the 3 results that this study concluded for 3 different strains of *Escherichia coli*. (TX432, H10407, and E6)

Pathogen	Water Type	Experiment Characteristics	Climate	Viability in Days		T90 or Log Reduction	Reference:
E. coli O157:H7 (10^3 CFU/ml and 10^6 CFU/ml)	Untreated river water (farm water)	5L of water was placed in 10L plastic containers sealed with lids.	Outdoors in a field	14	14[154]		McGee et al. 2002
			Ina field with bovine manure added (1% w/v)	10	24		
			In a farmyard shed	24	24		
			In a lab at 15°C	31	31		
E. coli O157:H7 (10^3 CFU/ml and 10^6 CFU/ml)	Sterile distilled water (autoclaved municipal water)	5L of water was placed in 10L plastic containers sealed with lids.	Outdoors in a field	10	17		MeGee et al. 2002
			In a field with bovine manure added (1% w/v)	21	28		
			In a farmyard shed	Still detectable at 31 days	Still detectable at 31 days		
			In a lab at 15°C	Still detectable at 31 days	Still detectable at 31 days		
E. coli O157:H7 (10^6/ml)	River water			Undetectable after 27 days.			Maule, 2000
E. coli O157:H7 (2.1 x 10^6 CFU/ml)	Bottled Spring Water	*E. coli* inoculated into 1L bottle of water.	22°C	Still detectable at 247 days.			Warburton et al. 1998
E. coli O157:H7 (6.3 x 10^5 CFU/ml)	Bottled Spring Water	*E. coli* inoculated into 1L of water.	22°C	Still detectable at 240 days.			Warburton et al. 1998
Escherichia coli nal-R (10^6 cells/ml)	Unfiltered river water	250mL water in a flask, in a dark environment	4°C	These values are T_{99} (time it takes to get a two-log reduction)		11.5d	K.P. Flint, 1987
			15°C			4.2d	
			25°C			2.5d	
			37°C			1.9d	
Escherichia coli nal-R (10^6 cells/ml)	Autoclaved river water	250mL water in a flask, in a dark environment	4°C	These values are T_{99} (time it takes to get a two-log reduction)		>260d	K.P. Flint, 1987
			15°C			>260d	
			25°C			>260d	
			37°C			60d	

[154] Since the viability in days is the same for both inoculation levels, the rate of decline is greater when inoculated with 10^6 CFU/ml..

Cryptosporidium

Pathogen Type	Water Type	Experiment Characteristics	Weather Characteristics (temp, rain, etc)	Viability in Days	T90 or Log Reduction	Reference:
Cryptosporidium	Sterile distilled water		-4°C	>84d		Olson et al. 1999
			4°C	>84d		
			25°C	70d		
Cryptosporidium	Autoclaved river water	Microcosm Erlenmeyers were placed at 5°C and 15°C in the dark at 100rpm.	5°C		0.010log^{10}/day	Medema et al. 1997
			15°C		0.006log^{10}/day	
Cryptosporidium	Natural river water		5°C		0.010log^{10}/day	Medema et al. 1997
			15°C		0.024log^{10}/day	
Cryptosporidium parvum (2.8 x 10^7 oocysts/container)	Tap water	Semi-permeable container put into the main water supply		After 176 days, 1% (2.8 x 10^5) of the oocysts were still alive.		Roberston et al. 1992
	River Water	Semi-permeable container submerged into a river.		After 176 days, 1% (2.8 x 10^5) of the oocysts were still alive.		

***Giardia*:**

Pathogen Type	Water Type	Experiment Characteristics	Weather Characteristics (temp, rain, etc)	Viability in Days	T90 or Log Reduction	Reference:
Giardia	Sterile distilled water		-4°C	<7d		Olson et al. 1999
			4°C	77d		
			25°C	14d		

***Salmonella*:**

Pathogen Type	Water Type	Experiment Characteristics	Weather Characteristics (temp, rain, etc)	Viability in Days	T90 or Log Reduction	Reference:
Salmonella typhimurium (1.6 x 10^7/ 25cm^2 pasture)	Non-chlorinated/ Non-sterile	1 litre of water mixed with 50g fresh sheep feces	Summer temps	3 x 10^3 at 70days[155]		Tannock and Smith, 1971
			Winter temps	100 at 84 days and then 5 at 98 days		
Salmonella (10^7 CFU/ml)	Groundwater	100ml glass flasks containing groundwater were incubated in the dark for 15 days.	22°C		10^5 CFU/ml in 15 days	Bitton et al. 1983

[155] This experiment was terminated at 10 weeks, therefore survival could have been longer.

Appendix 4.5: Transport of Pathogens in the Subsurface (vertical transport)

***Escherichia coli*:**

Pathogen	Manure Type	Climate	Location	Soil Type	Field Management Characteristics	Field/Lab Characteristics	Transport	Reference:
Fecal coliforms *indicator organism	Cattle slurry applied at a rate of $70m^3$/ha in the fall and $110m^3$/ha in the spring.	Outdoor study period of 4 years.	Ottawa, Canada	Clay loam, large site	Tile drains at a depth of 0.8m, incorporation		9 organisms/100ml[156] (2.8 x 10^4/100ml)[157]	Patni et al. 1984
				Clay loam, small site			8 organisms/100ml (6.7 x 10^3/100ml)	
				Sandy loam, small site			7 organisms/100ml (7.0 x 10^3/100ml)	
E. coli (5.3 x 10^4/g)	Dairy cattle slurry applied at a rate of $19.6m^3$/ha	Mid-March	East Central Scotland	Clay loam	2 plots of barley and 2 plots of pasture land	Drained plots (25cm deep)	25cm down to drainage within the 3rd and 7th days[158].	Fenlon et al. 2000
E. coli (10^{10} CFU/L)	*E. coli* suspension applied at a rate of $15m^3$/ha[159]	Outside Germany Oct 94-June 95	Germany	Loam to sandy	Plowed test field of $80m^2$		After 2 mths: 45-50cm deep After 3 mths: 95-100cm deep.[160]	Rothmaier et al. 1997
Fecal coliforms *indicator organism (1.0 x 10^8 – 4.6 x 10^9 CFU /soil block)	Poultry manure applied at a rate of 10t/ha	Blocks stored at 4°C. Rainfall at an intensity of 1cm/hr for 36hrs	Kentucky in lab.	Silt loam	Sod-covered, no-till, irrigated		42.5cm within 4 hours (2.3 x 10^7/100ml)	McMurry et al. 1998
					Tilled, irrigated		42.5 cm within 4 hours, although maximum numbers did not reach this depth until 22 hours[161].	

[156] These concentrations represent the geometric mean of the indicator bacteria in the tile drainage water.
[157] The concentrations in parentheses represent the maximum amount of indicator bacteria found in the tile drainage water.
[158] This transport led to a cumulative loss of *E. coli* to drains of 7% +/- 4% of applied *E. coli*. This would calculate to be 3.7 x 10^3 organisms/ml.
[159] This application rate was converted from the one given in the study of $15l/m^2$.
[160] At the 45-50cm depth, 13 organisms/g were detected, and at 95-100cm depth, 1 organism /g of soil was detected. The study concluded that although the persistence of the *E. coli* was found to last 7 months, it seems that the majority of the spread of the *E. coli* population could not survive long enough to be transported to soil levels greater than 50cm deep. 100cm was the maximum depth tested.
[161] After 22 hours of rain the leachate in the tilled soils contained over 2.0 x 10^7 CFU/100ml.

Pathogen	Manure Type	Climate	Location	Soil Type	Field Management Characteristics	Field/Lab Characteristics	Transport	Reference:
Fecal coliforms *indicator organisms	Dairy cow manure surface applied at a rate of 8.6-15.9t/ha	Spring 1993 to Winter 1995. 136 rain events.	Kentucky	Silt loam	No-till and Chisel Disked fields.		After the first rainfall, transport to at least 90cm[162].	Stoddard et al. 1998
Fecal coliforms *indicator organisms (1.8×10^4 orgs/ml)	Pig Slurry applied at a rate of $46m^3$/ha.	Average rainfall for January (78.4mm)	Northern Ireland	Silt loam	Plowed field		Within 30 minutes the bacteria had reached drains 1.5m deep. (3.6×10^3 orgs/ml)	Patterson et al. 1974.
E. coli 1.0×10^6/ml	Water containing biotracer (500ml per injection)		Oregon	Silty clay loam	Injected into field at a depth of 30cm	14% slope	150cm (10^2 cells/ml)	McCoy and Hagedorn, 1979
E. coli 5.3×10^4 /ml	Application of 40t/ha slurry	Outside in March	East Central Scotland	Clay loam	No indication of till or no-till	Grassland and arable land, each plot was $600m^2$	10% leached in 7d[163] (5.3×10^3/ml)	Ogden et al. 2001
E. coli 2×10^4/ml	Application of 50t/ha slurry			Silty clay loam			10% leached in 12d (2×10^3/ml)	
E. coli 1×10^5/ml	Application of 30t/ha slurry			Sandy loam			<0.2% leached in 90d[164] (2×10^3/ml)	
E. coli strain K-12, 10^7 cells/mL	Suspensions of *E. coli* in 0.005M $CaCl_2$	20mm/hr irrigation rate	Kentucky	Silt Loam		28cm deep intact soil columns	44%[165] got to 28cm (4.4×10^6/ml)	Smith et al. 1985
				Silt Loam			22% got to 28cm (2.2×10^6/ml)	
				Sandy Loam			79% got to 28cm (7.9×10^6/ml)	
				Silt Loam		28cm deep disturbed soil columns	7% got to 28cm (7×10^5 /ml)	
				Silt Loam			0.2% got to 28cm (2×10^4/ml)	

162 Transport to 90cm occurred in both tilled and no-till soils. The average amount of indicator organisms to enter the lysimeter pans in both the chisel-disked and no-till plots was 3×10^3 FC/100ml.

163 Leached to a depth of 25cm

164 There was little drainflow in this experiment therefore if weather conditions are dry after the application on well-drained sandy soils, it is unlikely that any significant losses of bacteria to drains will occur.

165 These percentages represent the amount of *Cryptosporidium parvum* oocysts that traveled through the 28cm soil column. It is easy to see that intact soil columns facilitate transport of the oocysts much better than disturbed soil columns.

Pathogen	Manure Type	Climate	Location	Soil Type	Field Management Characteristics	Field/Lab Characteristics	Transport	Reference:
				Sandy Loam			5% got to 28cm (5 x 10^5/ml)	
E. coli (9x10^5 CFU/ml)	Slurry applied at a rate of 57.67m^3/ha	8ºC, normal rainfall	In lab	Garden Soil		Packed plastic tubes	160cm[166]	Tamasi, 1981
		20ºC, normal rainfall					>160cm	
E. coli (9x10^5 CFU/ml)	Slurry applied at a rate of 57.67m^3/ha	8ºC, normal rainfall	In lab	Sand		Packed plastic tubes	110cm	Tamasi, 1981
		20ºC, normal rainfall					110cm	

***Cryptosporidium parvum*:**

Pathogen Type	Manure Type	Climate	Location	Soil Type	Field Management Characteristics	Field/Lab Characteristics	Transport	Reference:
Cryptosporidium parvum (1x10^8 per core)	No manure used	Simulated rainfall(70mL/h for 4 hrs)[167] Temp: 18º	In lab	Silty Loam	Intact soil cores (30cm x 15cm)	1cm depth	2.5x 10^5/g	Mawdsley et al. 1996a[168]
						10cm depth	2.8x10^4/g	
						20cm depth	1.8x10^4/g	
						30cm depth	9 x10^3/g	
Cryptosporidium parvum (1x10^8 per core)	No manure used	Simulated rainfall(70mL/h for 4 hrs) Temp: 18º	In lab	Loamy Sand	Intact soil cores (30cm x 15cm)	1cm depth	3 x10^4/g	Mawdsley et al. 1996a
						10cm depth	9 x10^3 /g	
						20cm depth	5 x10^3/g	
						30cm depth	3 x10^3/g	
Cryptosporidium parvum (1x10^8 per core)	No manure used	Simulated rainfall(70mL/h for 4 hrs)	In Lab	Clay Loam	Intact soil cores (30cm x 15cm)	1cm depth	3 x10^4/g	Mawdsley et al. 1996a
						10cm depth	6 x10^3/g	
						20cm depth	5.2 x10^3/g	

166 The amount of *E. coli* that reached this level is not given.
167 Irrigation was repeated every other day for a period of 21 days. After the 21-day study the soil cores were taken apart and sampled for oocysts at varying depths.
168 These results are taken from a graph in the journal article.

Pathogen Type	Manure Type	Climate	Location	Soil Type	Field Management Characteristics	Field/Lab Characteristics	Transport	Reference:
		Temp: 18°				30cm depth	4 x10^3/g	
Cryptosporidium parvum (1.7 x 10^9 oocysts/soil block)	Cow slurry applied at a rate of 50m^3/ha	Simulated rainfall of 3.4L 24hrs after application.	In Lab	Clay loam soil with grass intact	50m^3 /ha application rate, surface applied	7.5% in a tilting table apparatus.	Transport to 28cm within 1 day (10^7/ml) and continued to be found in leachate for 70 days (3.2 x 10^4/ml)	Mawdsley et al. 1996b

Salmonella:

Pathogen Type	Manure Type	Climate	Location	Soil Type	Field/Lab Management Characteristics	Field/Lab Characteristics	Transport	Reference:
Salmonella (10^5 CFU/ml)	Liquid Manure applied at a rate of 57.67m^3/ha	8°C, normal rainfall	In lab	Garden Soil		Packed plastic tubes	160cm[169]	Tamasi, 1981
		20°C, normal rainfall	In lab				160cm	
Salmonella (10^5 CFU/ml)	Liquid Manure applied at a rate of 57.67m^3/ha	8°C, normal rainfall	In lab	Sand		Packed plastic tubes	160cm	Tamasi, 1981
		20°C, normal rainfall	In lab				160cm	

169 The amount of *Salmonella* that reached these levels is not given.

Appendix 4.6: Tillage Effects on Survival and Transport

Pathogen	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability in Days or Log Reduction	Conclusion	Reference:
Fecal Coliforms	Dairy cow manure applied at a rate of 8.6-15.9t/ha.	No till and Chisel disk (conservation tillage)	Silt loam	136 rain events over the 2 year study in Kentucky		Tillage had no consistent effect on the concentration of fecal coliforms in the leachate.[170]	Stoddard et al. 1998
E. coli O157:H7 (3.0 x 10^7 CFU/ml)	Cattle manure applied at a rate of 6.12t/ha	Intact soil cores	Silty loam	25.4mm of rainfall per day for four consecutive days and then at four other times during the 18 day study		5.75 x 10^8 CFU/ml[171]	Gagliardi and Karns, 2000
			Clay loam			2.8 x 10^5 CFU/ml	
			Sandy loam			7.6 x 10^7 CFU/ml	
E. coli O157:H7 (4.7 x 10^7 CFU/ml)		Disturbed soil cores	Silty loam			6.7 x 10^7 CFU/ml	
			Clay loam			2.8 x 10^7 CFU/ml	
			Sandy loam			7.9 x 10^7 CFU/ml	
E. coli	Liquid swine manure applied at an average rate of 66.1m^3/ha	Surface Applied	Silt loam (tile drains at a depth of 0.87m)	Immediately following Application (tiles flowing)		2.3 x 10^6/100ml[172]	Wall et al. 1998
		Modified Injection				1.33 x 10^6/100ml	
		Conventional Injection				6.85 x 10^5/100ml	
		Surface Applied		Immediately following Rainfall (Rate of 3.2cm/hr)		6.0 x 10^5/100ml	
		Modified Injection				1.0 x 10^5/100ml	
		Conventional Injection				1.0 x 10^5/100ml	

[170] The average coliforms found in the no-till leachate and the tilled field leachate were not significantly different at 3 x 10^3 FC/100ml.

[171] These values represent the amount of E. coli that found in the leachate throughout the entire 18 day study. Some levels are greater than the initial inoculum levels which the authors suggest is growth of the organism due to moist soils after rainfall.

[172] All bacteria levels in tile drainage waters were taken within 6 hours.

Pathogen	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability in Days or Log Reduction	Conclusion	Reference:
		Surface Applied	Sandy loam (tile drains at a depth of 0.80m)	Immediately following Application (no tile flow)		6.5×10^4/100ml[173]	
		Modified Injection				5.0×10^3/100ml	
		Conventional Injection				4.9×10^4/100ml	
		Surface Applied		Immediately following Rainfall (Rate of 2.6cm/hr)		1.6×10^5/100ml	
		Modified Injection				9.75×10^4/100ml	
		Conventional Injection				9.75×10^4/100ml	
		Surface Applied	Silty clay loam (tile drains at a depth of 0.67m)	Immediately following Application (Half of tiles were flowing)		2.5×10^4/100ml	
		Modified Injection				1.22×10^5/100ml	
		Conventional Injection				1.18×10^5/100ml	
		Surface Applied		Immediately following Rainfall (Rate of 1.9cm/hr)		1.26×10^5/100ml	
		Modified Injection				2.98×10^4/100ml	
		Conventional Injection				1.13×10^4/100ml	
Brilliant Blue FCF Dye	None	No till	Silt loam		Avg. max. depth of dye flow: 364.8mm	This research confirmed the importance of continuous macropores in solute movement.	Vervoort et al. 2001
		Conventional tillage			Avg. max. depth of dye flow: 131.3mm		
Fecal coliforms	Cattle slurry applied at rate of 90-100m^3/ha	Immediate plowdown after application	Clay loam	4 yr study period outside of Ottawa		No statistical difference in quality of runoff between manured and non-manured land[174].	
	Non-manured						

[173] Bacterial levels in the tile drains in which no water was flowing were slightly less than those where water was flowing but still reached levels greater than primary water contact standards.
[174] The management practices that were used in this study appeared to be important factors that influenced the quality of runoff.

Pathogen	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability in Days or Log Reduction	Conclusion	Reference:
Fecal Coliforms (10-20000 CFU/g)	Poultry manure	Sod-covered, no-till irrigated with poultry manure at a rate of 10t/ha.	Silt loam	Rainfall (1cm/hr)	2.8x10^6 cfu/100mL after 8cm of rain[175]	Tilled soils retarded leachate but did not stop it, as coliforms were found in leachate after 22 hours.	McMurry et al. 1998[176]
		Tilled, irrigated with poultry manure at a rate of 10t/ha.			2x10^6 cfu/100mL after 22cm of rain[177]		
E. coli strain K-12, 10^7 cells/ml	Suspensions of *E. coli* in 0.005M $CaCl_2$	28cm deep intact soil columns	Crider Silt Loam	20mm/hr irrigation rate.	44%[178] got to 28cm (4.4×10^6/ml)		Smith et al. 1985
			Maury Silt Loam		22% got to 28cm (2.2×10^6/ml)		
			Bruno Sandy Loam		79% got to 28cm (7.9×10^6/ml)		
		28cm deep disturbed soil columns	Crider Silt Loam		7% got to 28cm (7×10^5 /ml)		
			Maury Silt Loam		0.2% got to 28cm (2×10^4/ml)		
			Bruno Sandy Loam		5% got to 28cm (5×10^5/ml)		
E. coli; nalidixic acid-resistant (10^6-10^{10}	*E. coli* tracer bacterium	Repacked soil columns; 8.9cm x 17.5cm	Silt loam	No macropores (n=4)		86.5% of the E.coli cells were recovered in the soil.[179]	Abu-Ashour et al. 1998

[175] Highest values observed of coliforms found in leachate.
[176] Where preferential flow occurred, fecal coliform movement also occurred. In a well-structured soil, groundwater contamination through soil may be significant during modest rainfall.
[177] Highest values observed of coliforms found in the leachate.
[178] These percentages represent the amount of *Cryptosporidium parvum* oocysts that traveled through the 28cm soil column. It is easy to see that intact soil columns facilitate transport of the oocysts much better than disturbed soil columns.
[179] The arithmetic average was taken of the individual experiment results.

Pathogen	Manure Type	Field/Lab Characteristics	Soil Type	Climate	% Viability in Days or Log Reduction	Conclusion	Reference:
CFU/ml)				1 artificially created macropore (n=2)		23.5% of the *E. coli* cells were recovered in the soil.	
E. coli; nalidixic acid-resistant (10^6-10^{10} CFU/ml)	*E. coli* tracer bacterium	Repacked soil columns; 8.9cm x 17.5cm	Loam	No macropores (n=2)		86.5% of the E.coli cells were recovered in the soil.[180]	Abu-Ashour et al. 1998
				1 artificially created macropore (n=4)		31% of the *E. coli* cells were recovered in the soil.	
E. coli; nalidixic acid-resistant (10^6-10^{10} CFU/ml)	*E. coli* tracer bacterium	Repacked soil columns; 8.9cm x 17.5cm	Silt loam	No macropores (n=2) + rain (120ml over 2 hr)		59.5% of the *E. coli* cells were recovered in the soil.	Abu-Ashour et al. 1998
				1 artificially created macropore (n=2) + rain (120ml over 2 hr)		18% of the *E. coli* cells were recovered in the soil.	
E. coli; nalidixic acid-resistant (10^6-10^{10} CFU/ml)	*E. coli* tracer bacterium	Repacked soil columns; 8.9cm x 17.5cm	Loam	No macropores (n=2) + rain (120ml over 2 hr)		149.2% of the *E. coli* cells were recovered in the soil[181].	Abu-Ashour et al. 1998
				1 artificially created macropore (n=2) + rain (120ml over 2 hr)		61.65% of the *E. coli* cells were recovered in the soil.	

[180] The arithmetic average was taken of the individual experiment results.
[181] This percentage above 100 indicates that no bacteria were able to travel through the soil when there were no macropores and water content was high.

Appendix 4.7: Transport of Pathogens in Runoff

***Escherichia coli*:**

Pathogen Type	Manure/Inoculum	Climate and Time of Year	Location of Study	Soil Type	Field Management Characteristics	Field/Lab Characteristics	Transport	Reference:
E. coli	Water containing biotracer (500ml per injection)		Oregon	Silty clay loam	Injected into the soil at 30cm depth	14% slope	10^2 cells/ml at 20.5m[182]	McCoy and Hagedorn, 1979
Acid resistant *E. coli* strain	Water containing biotracer (2 x 10^{12} CFU/40L)	Avg temps: 7-14°C. 2 days after application, heavy rainfalls were noted.	Northern Jordan	Clay loam; 20% soil water content	Spraying and no incorporation	2% slope	20m (15CFU/ml)	Abu-Ashour and Lee, 2000.
						6% slope	35m (16CFU/ml)	

[182] This distance is the cutoff of the experiment, transport may have continued.

***Cryptosporidium parvum*:**

Pathogen	Manure Type	Climate	Location	Soil Type	Field Management Characteristics	Field/ Lab Characteristics	Transport	Reference:
Cryptosporidium parvum	200g fecal pats (cattle) inoculated with 1 x 10^5/g[183] oocysts	4 rain events took place during the study period. (Feb 1 – Mar 15)[184]	California	78% sand, 18% silt, 4% clay.	Natural rangeland conditions	10% slope	112.5 oocysts/L/m [185]	Tate et al. 2000.
						20% slope	2587.5 oocysts/L/m	
						30% slope	9462.5 oocysts/L/m	
Cryptosporidium parvum (1.7 x 10^9 oocysts/soil block)	Cow slurry applied at a rate of $50m^3$/ha	Simulated rainfall of 3.4L 24 hours after application.	In lab	Clay loam soil with grass intact	Soil blocks were removed from the field intact. Field application rate of 50 m^3/ha	7.5% slope in a tilting table apparatus.	Oocysts were found in runoff (80cm transport) for 21days[186]	Mawdsley et al. 1996b

183 This level represents a relatively high shedding rate for calves.

184 Rain events ranged from 5mm to 10mm during the study period.

185 Mean number of oocysts in runoff, stratified by slope. Transport of C. parvum oocysts increases as slope increases, which the authors suggest to be the result of reduced filtration efficiency of the buffer strip subsequent to the larger volume and depth of water moving across the buffer.

186 When water was sprayed on the tables, *Cryptosporidium* oocysts went into an aqueous stage and were not available to adsorb to soil particles, they were more easily transported in runoff than through the soil matrix. Average numbers leached decreased from 8.36±0.56 x 10^6 at day 1 to 2.27±0.73 x 10^4 at day 70.

Appendix 4.8: Effectiveness of Vegetated Buffer Zones

Pathogen	Manure/Mixture Type	Climate	Soil Type	VBZ width	Log Reduction or Distance Traveled	Conclusion	Reference:
C. parvum (3 x 10^7 oocysts/ml)	Immunofluorescent assay.	If low to medium rainfall occurs (<4cm/hr)	Silty clay loam, loam, or sandy loam.	1m	1.0-3.1 $\log_{10}$ reduction	To reduce C. parvum to acceptable levels a VBZ of 3-7m is required.[187]	Atwill et al. 2002
TC ($10.5x10^5$-$4.92x10^6$ cfu/100ml) and FC ($7.0x10^5$-$15.8x10^5$ cfu/ml)	Swine lagoon wastewater applied at a rate of 86.7m^3/ha.	Studied a whole season	Loamy sand	30.0m[188] with a slope of 1.5-2.0%.	2.0-3.0 $\log_{10}$ reduction	TC and FC numbers were reduced by 2-3 logs in a 30m buffer[189].	Entry et al. 2000
Fecal Coliforms	Poultry manure that was incorporated at a rate of 16.5t/ha.	Rainfall simulated 1 week after appl. (6.4cm/h)[190]	Silt loam	9.0m with a 9% slope.	74% reduction	VBS only trapped up to 74% of the fecal coliforms.[191]	Coyne et al. 1995
Total Coliforms (9.0 x 10^7)	Feedlot runoff	25yr/24hr rainfall (6.35cm/hr for 71 minutes)		27m with a 4% slope[192]	69% reduction	A 35.44m long buffer strip would be required to reduce to acceptable levels. [193]	Young et al. 1980.
Fecal Coliforms (7.6 x 10^6)					69% reduction		

[187] Authors note that VBZ of similar soils with bulk density of 0.6-1.7 g/cm3, 20% slope or less, and widths of at least 3m should generally function to remove 99.9% of C. parvum oocysts from overland flow during low to moderate precipitation and suggest 3-7m.
[188] Three types of vegetated buffer zones were examined: 1) 20m grass, 10m forest; 2) 10m grass and 20m forest; 3) 10m grass and 20m maidencane. Maidencane is a species recommended for constructed wetlands.
[189] Based on the number of FC and TC that were inoculated, these log reductions would not meet water quality standards. The authors note that during dry periods in the summer and fall, TC and FC did not move past 15m in any of the buffer zones.
[190] This rate of rainfall is considered to be a 1 in 10 year storm in Kentucky, therefore heavier rainfall was simulated.
[191] The vegetated buffer strips were efficient at trapping sediment loads, and trapped 99% of the soil in the runoff from the erosion strips. These results cannot be uniformly extended to fecal coliforms in the same runoff, the strips only trapped up to 74% of the fecal coliforms. This may have to do with size differences. Fecal coliforms were found in the runoff at greater than 200/100ml.
[192] There were three different buffer strips tested: 1) 13.72m long, 2) 27.43m long + 13.72 m of feedlot, and 3) 21.34 m long and 13.72 m of feedlot. Total Nitrogen and Total Phosphorous were reduced by 83 and 84%, respectively.

Pathogen	Manure/Mixture Type	Climate	Soil Type	VBZ width	Log Reduction or Distance Traveled	Conclusion	Reference:
Fecal coliforms (2×10^7 FC/100mL)	Cattle manure applied at a rate of 60kg N/ha	Rainfall intensity of 100mm/hr.	Silt loam	18.3m, 100% cover, 10cm height	100% after 6.1m[194]		Lim et al. 1998
Total Suspended Solids (TSS)	Liquid Swine manure applied at a rate of 200kg N/ha	Rainfall intensity of 50mm/hr. .	Silt loam	0m	61.7mg/L	There was no significant increase in the effectiveness of VFS beyond 3m.	Chaubey et al. 1994
				3m[195]	12.1mg/L		
				6m	11.4mg/L		
				9m	8.7mg/L		
				15m	9.5mg/L		
				21m	5.3mg/L		
Fecal coliforms (11.5×10^5 CFU/100ml)				0m	11.5×10^5CFU/100ml	The vegetated strip did not significantly reduce mass transport of FC.	
				3m[196]	7.5×10^4CFU/100ml		
				6m	21.7×10^4CFU/100ml		
				9m	12.6×10^4CFU/100ml		
				15m	11.5×10^4CFU/100ml		
				21m	15.2×10^4CFU/100ml		
Fecal coliforms (2.3×10^5 FC/g)	Simulated Model used. Manure spread at 2.2t/ha		Silt loam	100feet (30.48m) with a 3% slope		All water samples were > than 10^2 FC/100mL[197]	Walker et al. 1990

[193] Recommended bacteriological standards for surface waters for the public water supply and general recreational use are 1,000 TC/100mL and 200 FC/100mL. (Based on a United States Department of Interior report on water quality.)
[194] After a filter length of 6.1m the runoff exhibited no measurable concentration of fecal coliforms.
[195] The average effectiveness of VFS computed for all lengths and replications was 61% for TSS.
[196] The average effectiveness of VFS computed for all lengths and replications was 58% for FC.
[197] The vegetative filter strips alone were not adequate to meet the recreational water quality standard of 200 FC/100ml, in all water samples taken, FC were greater than 200/100ml.