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Biosecurity in agriculture [electronic resource] : a suggested strategy for the protection of source water against pathogenic contamination

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BIOSECURITY IN AGRICULTURE:
A SUGGESTED STRATEGY FOR THE PROTECTION OF SOURCE WATER AGAINST PATHOGENIC CONTAMINATION

by

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ABSTRACT

To reduce the threat of pathogenic responses in humans, the Government of Ontario has introduced the *Clean Water Act*. The Act is intended to identify, characterize, and mitigate risks to vulnerable sources of drinking water. Applying the appropriate level of protection in those areas where land use activities contribute to the contamination of source water can be achieved through the use of biosecurity strategies comprised of operational measures to treat manure prior to storage and handling. Recent outbreaks of waterborne disease linked to manure management practices has resulted in an increased awareness of the potential risks that livestock operations pose to source water quality. This investigation demonstrated that currently available treatment technologies can significantly reduce pathogen concentrations in livestock manure; however the extent that these measures can be integrated into the proposed *Clean Water Act* is limited by the lack of controlled, replicated studies conducted at the commercial-scale.

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Dedication

For Mary Ann and Edward Earl, my parents.

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CHAPTER ONE: INTRODUCTION

1.0 Overview

A wide variety of human activities can contribute to the pathogenic contamination of source water. The presence of bacteria, protozoa, and viruses in drinking water supplies can cause pathogenic responses in humans leading to illness, and in some instances, death. Human illness and death caused by waterborne pathogens can be avoided by applying the appropriate level of protection in those areas where land use activities contribute to the contamination of source water. To reduce the threat of pathogenic responses in humans, the Government of Ontario has developed a legislative framework based on a multi-barrier approach that considers risks from source to tap. The framework is currently supported by regulations for treatment, distribution, monitoring, and response programs that minimize or prevent pathogenic contamination in drinking water systems. The proposed *Clean Water Act* intends to address source water protection through the identification of significant drinking water threats and the development of risk management strategies.

Recent outbreaks of waterborne disease linked to manure management practices suggest that agricultural operations will be identified as a significant threat to source water quality. Historically, manure management has focused on nutrient retention and waste disposal with emphasis placed on eliminating or reducing problems associated with odours and aesthetics. Pathogen abatement is becoming an increasingly important consideration in manure management programs as the impacts to source water quality are investigated. The literature suggests that the survival and movement of pathogens is highly specific to the pathogen, as well as soil and water conditions. Due to variability in pathogen survival, efforts to protect source water must be based on empirical evidence. Several reviews of both regulatory and voluntary measures to minimize pathogenic contamination indicate that there is a lack of scientific evidence to support operational requirements.

Given that the microbiological quality of water is considered to be one of the most important factors when assessing water quality, there is an apparent need for a legislative framework supported by regulations that outline systematic methodology to prevent pathogenic loadings in source water. The methodology employed in traditional biosecurity programs for the control and eradication of disease in livestock may translate to the control and eradication of pathogens in source water.[1] Operational measures, such as manure treatment prior to storage and handling, may offer a level of pathogenic reduction to address and eliminate drinking water threats in agricultural areas. A review of the efficacy of currently available technologies requires further investigation to determine the anticipated level of pathogenic reduction. While a framework for the development of plans to protect source water has been designed, a strategy for mitigating threats is not yet available. Programs that consider available technologies for pathogen inactivation in manure prior to storage and handling should be given consideration if the intended goals of the *Clean Water Act* are to be met.

1.1 Proposed Hypothesis

Biosecurity strategies can effectively contribute to source water protection from pathogenic contamination in agricultural operations.

The overall objective of this research is to suggest a role for biosecurity measures in the identification and mitigation of pathogenic risks and to determine how these measures fit in with existing and proposed legislation in the Province of Ontario.

1.2 Purpose and Objectives

The research is intended to address the following questions:

1. What is the estimated level of pathogenic reduction achieved from currently available manure treatment technology?

A review of currently available scientific evidence of manure treatment technologies will assist in determining which technologies have demonstrated pathogen inactivation capabilities. An investigation of the empirical evidence of technologies applied at the field-scale will determine the estimated level of pathogenic reduction that can be achieved in manure.

[1] For the purposes of this paper, "livestock" refers to all animals, including poultry.

2. What is the expected efficacy of a biosecurity strategy at preventing pathogenic loading in source water?

A review of existing biosecurity programs is intended to introduce the elements of traditional biosecurity programs and determine the efficacy of translating the framework to source water protection.

3. To what extent could a biosecurity strategy be integrated into proposed legislation?

The significance of the proposed biosecurity strategy will be assessed against the proposed *Clean Water Act* and opportunities for integration will be determined.

Focusing on these three areas of interest is intended to critically assess how effective biosecurity measures are in the prevention of pathogenic loading in source water in agricultural operations.

1.4 Outline

Research and analysis conducted for this thesis has been divided into the following chapters:

<u>Chapter 2 – Source Water Protection</u>

Chapter 2 presents an historical account of the development of source water protection in Ontario. The review draws on existing pieces of legislation and outlines stakeholder roles and responsibilities for the proposed *Clean Water Act*. Weaknesses in the current legislative framework regarding risk management strategies are identified. A review of programs and policies governing manure management in other jurisdictions is conducted to facilitate an improved understanding of source water protection. Trends in animal husbandry practices are also highlighted to demonstrate the increasing potential for water quality impacts in agricultural areas.

Chapter 3 – A New Role for Biosecurity

Chapter 3 defines the concept of biosecurity and illustrates its efficacy in the prevention and irradiation of disease in livestock. A jurisdictional review of programs and policies governing biosecurity is conducted to facilitate an improved understanding of the scope of biosecurity.

Chapter 4 – Notifiable Diseases

Chapter 4 illustrates the relationship between waterborne disease outbreaks and agricultural sources. Trends in waterborne disease rates in Canada are highlighted. Notifiable waterborne diseases in Ontario and their associated causal agents are identified. Relevant pathogens are ranked according to persistence and prevalence to determine which pathogens present the greatest threat to source water quality in agricultural areas.

Chapter 5 – Pathogen Inactivation in Manure

Chapter 5 illustrates the trends in manure management and clarifies the differences in the collection, storage, and application of manure. Physical, chemical, and biological treatment methods are discussed in general. A review of currently available manure treatment technologies is presented to determine the estimated levels of pathogenic inactivation. A brief discussion of alternative uses for manure is also provided.

Chapter 6 – Applying the Biosecurity Model

Chapter 6 draws on the conclusions reached from the review of manure treatment technologies to suggest the expected efficacy of a biosecurity strategy at preventing pathogenic loading in source water. The expected reduction in microorganism prevalence is presented along with a cost/unit analysis to determine practicality of implementation. Factors affecting the selection and implementation of treatment technologies are addressed and the extent that the biosecurity strategy could be integrated into proposed legislation is discussed. The common elements that contribute to a successful biosecurity program are discussed and a framework for source water protection is presented.

CHAPTER TWO: SOURCE WATER PROTECTION

2.0 Protecting Drinking Water Quality in Ontario

The pathogenic contamination of source water due to agricultural practices has been widely recognized as a non-point source of contamination that has not been adequately managed in Ontario. Despite taking steps in January of 2000 to determine the direction that the Province should take in managing non-point sources of pollution, regulatory frameworks to address this problem had not yet been established.[2] Later that same year seven deaths occurred in the town of Walkerton when drinking water supplies were contaminated with *Escherichia coli.* Shortly after the tragic events in Walkerton, an investigation of the possible causes of the drinking water contamination was initiated. The Walkerton Commission of Inquiry revealed that the source was likely manure run-off from an agricultural operation. Immediate action was taken to evaluate methods of protecting provincial drinking water sources from future contamination. Justice Dennis O'Connor was assigned the task of preparing recommendations based on the findings from the Walkerton Commission of Inquiry. Among those recommendations was a multi-barrier approach that would require a review of current legislation and the development of new laws that would compliment each other to ensure safe drinking water supplies. Source protection is considered to be the first of five barriers to protect drinking water (Figure 2.1). The remaining barriers include: (a) treatment, (b) distribution systems, (c) monitoring programs, and (d) response to adverse conditions (O'Connor, 2002; pg. 73).

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[2] The Joint Task Force on Intensive Livestock Operations was assembled in January of 2000 by the Ontario Ministry of Agriculture, Food, and Rural Affairs and the Ontario Ministry of the Environment to collect information and solicit comments from stakeholders and the general public to determine the direction that the Province should take in regulating non-point sources of pollution, specifically nutrients.

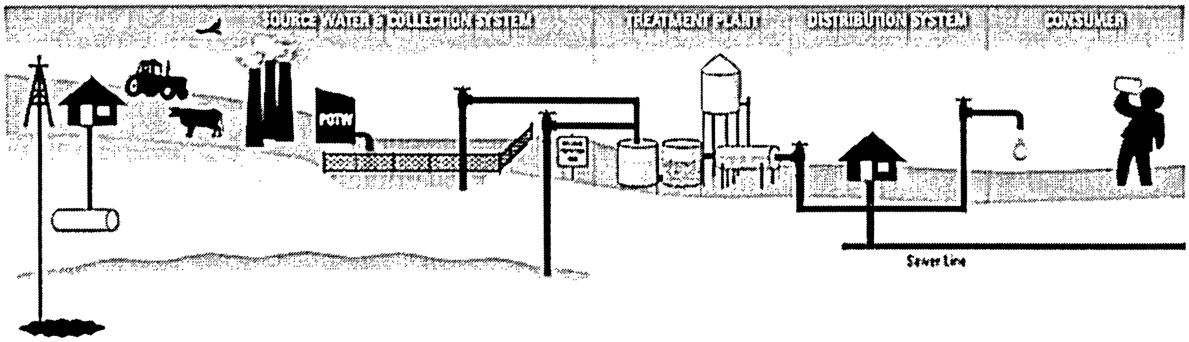

Figure 2.1: The Multi-Barrier Approach
Source: United Stated Environmental Protection Agency. Office of Ground Water and Drinking Water. (2002b). *Consider the Source: A Pocket Guide to Protecting Your Drinking Water – Drinking Water Pocket Guide # 3* (EPA 816-K-02-002). Washington, DC: Author; p. 2.

The ultimate goal of source water protection is to keep raw water as clean as possible (O'Connor, 2002) to reduce the reliance on treatment and response barriers. The barriers work collectively, however, to ensure there is some redundancy in the treatment of source water. If one barrier fails, the risk of contamination is minimized by the efficacy of the remaining barriers. Today, there is recognition that the development of watershed management strategies must consider other factors to achieve the goal of maintaining raw water as clean as possible. The planning process must be supported by scientific evidence of pathogen origins, fates, and transport and consideration of human activities in the boundaries of the watershed (Conservation Ontario, 2003) in order maintain a high degree of water quality.

There are a number of parameters that are used to evaluate the quality of water. In Ontario, the objective is that "water intended for human consumption shall not contain disease causing organisms or unsafe concentrations of toxic chemicals or radioactive substances. Water should also be aesthetically acceptable and palatable" (Ontario Ministry of the Environment, 2003; p.1). These parameters are quantified as part of water sampling and analysis programs. The results are then compared to water quality standards to determine if the water is fit for human consumption. The microbiological quality of water is considered to be one of the most important factors when assessing water quality. This is due to its association with waterborne diseases such as typhoid fever, cholera, enteroviral disease, bacillary and amoebic dysentery, and many varieties of gastrointestinal diseases (Ontario Ministry of the Environment, 2003).

In Ontario, the *Safe Drinking Water Act* (2002) requires that all owners of a municipal drinking water system or a regulated non-municipal drinking water system comply with the microbiological standards set out in Schedule 1 of Ontario Regulation 169/03 (Ontario Drinking Water Quality Standards).[3] In addition, Ontario Regulation 170/03 (Drinking Water Systems) requires that both large and small municipal drinking water systems operate in accordance with the Ministry's Procedure for Disinfection of Drinking Water in Ontario. Recent amendments to Schedule 1 of O. Reg. 169/03 were made to eliminate standards for those parameters that have been deemed as outdated, or that are no longer considered to be health-related by the scientific and technical community (Ontario Ministry of the Environment, 2006b). This revision resulted from a review by the Advisory Council on Drinking Water Quality and Testing Standards. The Advisory Council was created under the *Safe Drinking Water Act* (2002) and its mandate is to advise the Minister of the Environment on standards (including drinking water standards, aesthetic objectives, guidelines, performance standards, and procedures), legislation, regulations, and relevant issues. The amendments resulted in the removal of fecal coliforms, general bacteria population expressed as background colony counts on the total coliform membrane filter, and general bacteria population expressed as colony counts on a heterotrophic plate count (HPC) from the microbiological standards (Table 2.1).[4]

Table 2.1: Ontario Drinking Water Quality Microbiological Standards

Microbiological Parameter	**Standard (expressed as a maximum)**
Escherichia coli (E. coli)	Not detectable
Revoked: O. Reg. 248/06, s. 1	
Total coliforms	Not detectable
Revoked: O. Reg. 248/06, s. 1	
Revoked: O. Reg. 248/06, s. 1	

Source: Ontario Regulation 169/03; Schedule 1.

There are currently no microbiological standards set for protozoan pathogens in Ontario Regulation 169/03. Recommendation # 28 from the Walkerton Commission of Inquiry advised that "[n]o formal maximum contaminant level for protozoa should be established until real-time

[3] *Safe Drinking Water Act*, S.O. 2002, c. 32, s. 11(2).

[4] In the previous standards, general bacteria population expressed as background colony counts on the total coliform membrane filter had a maximum standard of 200 colony forming units (CFU) per 100 millilitres, general bacteria population expressed as colony counts on a heterotrophic plate count had a maximum standard of 500 colony forming units (CFU) per millilitre, and the standard for fecal coliforms was non-detectable.

tests are available. The objective, as with bacterial and viral pathogens, should be zero, and the regulations should so state; but the standard should be a treatment standard, specified in terms of log removal dependent on source water quality" (O'Connor, 2002; p. 164). A lack of consistency and reliability in monitoring for protozoan organisms in water supplies has lead to serious outbreaks of disease. As such, O'Connor (2002) advocated that standards for these organisms be based on performance criteria for treatment methods rather than reporting on the absence of microbes from water supplies. Currently, Ontario's Protozoa Treatment Standard exists in the Procedure for Disinfection of Drinking Water in Ontario and states that the treatment process must achieve overall performance that provides a minimum 2 log (99%) reduction removal or inactivation of *Cryptosporidium* oocysts and a 3 log (99.9%) reduction removal or inactivation of *Giardia* cysts prior to the delivery of water to the first consumer (Ontario Ministry of the Environment, 2006a; pp. 3-4). Given that drinking water disinfection is specific to the raw water quality entering the treatment system, all water supplies should be assessed by measuring water quality parameters (Ontario Ministry of the Environment, 2006a) in order to ensure that the performance of the treatment system is meaningful.

Despite improvements made to disinfection processes and standards, many microbiological contaminants can remain viable in water treatment and distribution systems due to their highly resistant nature. One way to further ensure safe supplies of drinking water and to reduce operating costs is to prevent the introduction of pathogenic contaminants at the source. In rural communities, the development of land use restrictions on the establishment of new and expanding livestock operations has been commonly used to prevent pathogenic contamination of source water. For instance, extensive groundwater studies conducted in the early 1990s in Oxford County identified five sensitive aquifer areas that were designated as Groundwater Recharge Areas. The Official Land Use Plan was amended to include these areas and protect them through the restriction of specific land uses thought to potentially impact groundwater quality. The result has been the establishment of a comprehensive watershed management strategy aimed at protecting source water. Further development of water protection policies in Oxford County was triggered by an application made in 1997 for a hog barn to house 10, 000 head (Environment Canada, 2004; Section 4).[5] Mapping exercises conducted in the region

[5] Head refers to a single animal.

indicated that the proposed livestock operation would fall within a capture zone; an area surrounding a well that supplies groundwater, possibly posing a risk of groundwater contamination.

Due to growing concerns over odour and impacts to ground water quality, the County passed an interim control by-law prohibiting the establishment of new livestock operations with over 500 Nutrient Units (Environment Canada, 2004; Section 4).[6] Shortly after, the townships in Oxford County passed identical nutrient management by-laws that regulated manure management and the location and use of stables, barns, and manure pits. At the same time, zoning by-laws were amended to include provisions on minimum separation distances between new or expanding livestock barns and neighbours, as well as requirements for nutrient management plans for new or expanding intensive livestock operations. Following the completion of groundwater protection studies, new planning policies for Oxford County's Official Land Use Plan were developed. The Groundwater Protection Strategy was incorporated into the plan and relies on both aquifer and wellhead protection to: (a) limit the risk of contamination from historical, existing, or future land uses by restricting land uses in sensitive areas around municipal water supply wellheads and vulnerable aquifer areas, (b) manage water quantities to ensure that the quantity used does not exceed recharge capacity by integrating water budgets, conservation plans, and reviews of high water users and proponents of new municipal well supplies, and (c) promote water conservation through public education and water restriction by-laws (Environment Canada, 2004; Section 5.2.6).[7]

A number of other communities have taken a similar approach by restricting farming practices through the use of municipal by-laws. Since municipalities have no direct constitutional authority, their regulatory powers are provided to them through a number of Provincial Acts including the *Planning Act* (1990), *Municipal Act* (2001), and the *Building Code Act* (1992). Amendments in zoning, building permits, and the regulation of nuisances such as noise, odour, and dust have generated a number of by-laws that are capable of restricting various farming

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[6] The Nutrient Unit (NU) is the amount of manure that gives the fertilizer replacement value of the lower of either 43 kg of nitrogen or 55 kilograms of phosphate generated by the type of animal (Ontario Ministry of Agriculture and Food, 2005a; Section 3). For instance, one beef cow, eight goats, or 150 laying hens would be the equivalent of one NU (Appendix 2.1).

[7] Lands located within Well Head Protection Areas may be used as designated, but are subject to prohibitions or additional requirements and/or restrictions depending on the risk to the water supply.

practices. The formation of such by-laws was due in part to revisions and regulatory gaps in existing legislation. For instance, the *Environmental Protection Act* (1990) sets emission standards and most frequently governs chemical contamination in source water rather than pathogenic contamination that may result from agricultural practices. Furthermore, the general provisions of the *Environmental Protection Act* (1990) were revised to exempt farmers from impairment to the natural environment if animal wastes are disposed of in accordance with normal farming practices as outlined in the *Farming and Food Production Protection Act* (1998).[8] The *Farming and Food Production Protection Act* (1998) defines "normal" as being consistent with proper and acceptable standards by similar agricultural operations under similar circumstances, or using innovative technology with proper management plans.[9] Despite this exemption, farmers remain liable for adverse affects to human health or property resulting from farming practices.

The Federal *Fisheries Act* (1985) deals primarily with habitat protection for aquatic species and has been seldom used for source water protection. The Act contains two powerful prohibitions against the harmful alteration, disruption, or destruction of fish habitat and the discharge of deleterious substances into water frequented by fish, but surprisingly, there have been very few prosecutions of farming practices made under the *Fisheries Act* (1985) in Ontario (McRobert and Hopkins, 2004) despite its potentially broad application.[10] Another powerful law capable of restricting farming practices is the *Ontario Water Resources Act* (1990). Like the *Fisheries Act*, the *Ontario Water Resources Act* (1990) contains a general prohibition against the discharge or deposition of material of any kind into a waterbody or water course that may impair water quality.[11] This piece of legislation is frequently used to prosecute individuals involved in large manure spills (McRobert and Hopkins, 2004).[12] While these existing pieces of Federal and Provincial legislation do provide for the protection of source water, they fail to target the potential impacts of pathogenic contamination of surface and ground water supplies.

[8] *Environmental Protection Act,* R.S.O. 1990, c. E.19, s. 6(2).
[9] *Farming and Food Protection Act*, S.O. 1998, c. 1, s. 1.
[10] *Fisheries Act*, R.S. 1985, c. F-14, s. 35 (1) and 36 (3).
[11] *Ontario Water Resources Act*, R.S.O. 1990, c. O.4, s. 31.
[12] Charges were laid in October, 2002 in Chatham, Ontario after DeBrower Farms caused the contamination of surface drains flowing into Rondeau Bay with liquid hog manure. The Ministry of the Environment conducted an investigation after receiving a number of complaints regarding the incident and charged DeBrower Farms with the discharge of material that contravened Section 30 (1) of the *Ontario Water Resources Act* (1990). DeBrower farms pleaded guilty to the charge and were fined $7500 (Ontario Ministry of the Environment, 2002).

Furthermore, these frameworks operate retroactively by administering fines and penalties after environmental impacts have already occurred. As such, there is a clear need for a legislative framework supported by regulations that outline a systematic method to prevent pathogenic loadings in source water.

Much of the direction for protecting Ontario's drinking water sources has been encouraged through voluntary measures. In 1993, the Ontario Ministry of Agriculture, Food, and Rural Affairs implemented the Environmental Farm Plan Program and developed a number of provincial guidelines known as Best Management Practices (BMPs). The Environmental Farm Plan Program was established to highlight environmental strengths, identify areas of environmental concern and to help set realistic goals for improvement (McRobert and Hopkins, 2004). To encourage the protection of both environmental and human health in agricultural areas, many municipal by-laws required that these provincial guidelines be applied to farming operations. Other communities, like Oxford County, required farm operators to meet additional requirements to address concerns about source water contamination, such as the preparation of Nutrient Management Plans. However, the use of BMPs has proven to be ineffective at controlling the contamination of source water. The contamination of drinking water supplies with *Escherichia coli* 0157:H7 in Walkerton was determined to be the result of an outbreak in a livestock operation located in a well water capture zone. The operator, Dr. Biesenthal managed the handling, storage, and spreading of manure using BMPs established by the Ontario Ministry of Agriculture, Food, and Rural Affairs (O'Connor, 2001).[13] Many BMPs, including those used in Ontario, are not supported by the scientific evidence necessary to provide protection against the introduction of pathogens into surface and ground water supplies. For instance, both the survival and transport of pathogens are often overlooked as variables in the development of BMPs despite their role in prolonging infectivity. Furthermore, differences in livestock, operating practices, soil characteristics, and topographical features make the application of uniform management practices impractical. A stronger emphasis should be placed on the development of policies and programs that are supported by scientific evidence and that can be customized according to individual farms.

[13] From 1999-2000, the livestock operation consisted of a breeding herd of 40 cows and heifers and were housed in a barn from December to April. In late spring, animals from other operations were brought onto the farm for sale, increasing the livestock population to a maximum of 95 head (O'Connor, 2001; p. 128).

2.1 Taking the First Steps – The Nutrient Management Act

In response to findings from both the Task Force on Intensive Livestock Operations and Justice O'Connor, the *Nutrient Management Act* (NMA) was granted Royal Assent on June 27, 2002. Designed as enabling legislation, the NMA seeks to develop regulations that will align with the ultimate goal of protecting surface and groundwater from damaging nutrient concentrations. The Act defines the purpose as the "management of materials containing nutrients in ways that will enhance protection of the natural environment and provide a sustainable future for agricultural operations and rural development".[14] The broad application of the purpose of the Act and the definition of nutrient suggests that the potential exists for the development of a number of regulations. Currently, only Ontario Regulation 267/03 (General) has been passed. This regulation came into force on September 30, 2003 and outlines the handling and storage requirements for the use of nutrients in agricultural operations.

The most intensive requirements made within the Regulation fall under the Nutrient Management Protocol and involve the development of Nutrient Management Plans and Nutrient Management Strategies. While strategies and plans address different aspects of agricultural operations, both incorporate the use of methodologies that quantify nutrient loads. As a result, the Regulation provides a consistent approach to nutrient management regardless of variations among individual farms. The nature and level of source water protection achieved by Nutrient Management Plans and Strategies is, however, questionable. Both Strategies and Plans appear to fill administrative requirements, rather than adequately protect source water supplies. Nutrient Management Plans guide the application of nutrients and require specific information on the topographical features of the land, species of crops affected, and timing and rates of application. In comparison, Nutrient Management Strategies require information on the generation of nutrients and require detailed information on how the nutrients will be stored (Table 2.2).

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[14] *Nutrient Management Act*, S.O. 2002, c. 4, s. 1.
Under the *Nutrient Management Act* (2002), the term nutrient is defined as fertilizer, organic materials, biosolids, compost, manure, septage, pulp and paper sludge, and other material applied to land for the purpose of improving the growing of agricultural crops (S.O. 2002, c.4, s. 2).

Table 2.2: General Requirements of Nutrient Management Strategies and Plans

Nutrient Management Strategy	**Nutrient Management Plan**
Farm unit information and identifier numbers	Farm unit information (includes printouts of information from NMAN software)
Description of the Operation	Farm unit declaration
Farm unit declaration	Agreements
Agreements	Farm unit sketch
Farm unit sketch	Field sketch
List of prescribed materials generated	Soil test results
Analysis of nutrient content	Contingency plan
Destinations of nutrients generated	Sign off form
Storage information (amount, residency)	
Contingency plan	
Sign-off form	

Source: Ontario Ministry of Agriculture, Food, and Rural Affairs. (2005a). *Nutrient Management Protocol*; Section 4.2.

The availability of funding for farming practices continues to be a controversial subject surrounding the NMA. The current funding program has been widely criticized for a lack of timely and efficient delivery. In addition, to ensure full cooperation with the agricultural community, immediate attention must be directed to improving communication among stakeholders. Efforts should be focused on providing the most accurate and comprehensive information through a variety of media in order to reach the target audience.

The development of effective communication strategies has been an area of interest for many researchers. Audsley *et al.* (2004) recently developed a program targeted at farmers in Scotland intended to raise awareness about pollution arising from agricultural land use activities and mitigation strategies. The program was delivered as a pilot test to address its strengths and weaknesses. The pilot test revealed that a lack of financial support and incentives was an obstacle in implementing the guidelines identified in the program. Davies and Mazumder (2003) conducted a review of the source water protection policies and drinking water treatment systems currently in place in British Columbia. Their review reached similar conclusions stressing that efforts should be placed on promoting the economic and health benefits of protecting source waters through incentive programs.

2.2 Developing Source Water Protection Legislation

Following the recommendations made by Justice O'Connor, two separate committees were formed to address technical and implementation issues. The intention of the Watershed-based Source Protection Planning Technical Experts Committee was to "provide advice on the identification and effective means of addressing possible threats to drinking water" (Watershed-Based Technical Experts Committee, 2004; p. 6B-1). Due to the technical nature of many issues, sub-committees were also formed to fully address well vulnerability, aquifer vulnerability, pathogen risks, the application of Geographic Information Systems (GIS), and naturally vegetated areas. At the same time, the Minister of the Environment also formed the Watershed-Based Source Protection Implementation Committee to ensure that source water protection legislation was implemented in a timely and efficient manner. The Implementation Committee was comprised of members of the scientific community, farming associations, environmental organizations, federal and provincial regulatory agencies, and municipalities. Their mandate was to provide advice on implementation tools, roles and responsibilities of stakeholders, and funding mechanisms for proposed legislation (Watershed-Based Implementation Committee Implementation Committee, 2004).

The leadership and innovation in water protection displayed by Oxford County has been used to guide the direction for similar policies and practices, including the development of the *Nutrient Management Act* and the proposed *Clean Water Act*. The success achieved in Oxford County is attributed to a number of factors including: (a) public and private commitment, (b) support from the Ontario Ministry of the Environment, (c) a balance between concern and development needs, (d) technical support, (e) inclusiveness, (f) data sharing, and (g) targeting of specific issues (Environment Canada, 2004). As expected, many of the same factors that contributed to the success of Oxford County are outlined in the Implementation Committee's report to the Minister of the Environment. Additional expectations for the final legislative framework include aspects of sustainability, comprehensiveness, cost effectiveness, and a phased-in approach. Furthermore, the Implementation Committee stresses that the responsibility of source water protection be shared by all levels of government with accountability clearly defined.

2.2.1 Areas of Concern

The threats inventory and issues identification exercise was a critical step in establishing effective source water protection programs for the province. Twenty-four specific issues were identified by the Implementation Committee as potential risks to source drinking water and a number of specific activities have been identified as potential threats to water quality. Potential threats to drinking water sources in rural areas include fuel and chemical storage tanks, septic systems, wells, pesticide use, and pathogen sources. Among these threats, pathogenic contamination of source water was given considerable attention. The focus on pathogenic contamination is due in large part to recent outbreaks of human illnesses and death that have resulted from microbiologically-contaminated drinking water. By understanding the behaviour of pathogens, disease outbreaks can be avoided (Watershed-Based Technical Experts Committee, 2004). Major pathogen sources identified during the exercise included the storage and application of biosolids, septage, and manure as well as infrastructure and processes related to sanitary sewage and septics. Issue-specific implementation tools and recommendations related to risk management were developed for agricultural activities. The recommendations are summarized in Table 2.3.

Table 2.3: Specific Agricultural Issues and Recommendations Identified by the Technical Experts Committee

Specific Issues	Recommendations
Land Application of Biosolids and Septage	• Bans on the use of untreated septage for land application and the development of standards for the application of treated septage • Incentives and financial assistance for septage treatment costs • Revisions to existing standards
Manure Application and Storage	• Co-ordinate with the *Nutrient Management Act* (2002) • Revise existing standards to include drinking water source protection and human health objectives • Manure storage and application should follow provincial standards and source protection plans
Farm Water Protection Plans (FWPP)	• Collaboration between Ontario Ministry of Agriculture, Food, and Rural Affairs and the Ontario Ministry of the Environment in planning • Investigate policy issues and costs related to FWPP • Streamline planning and approval processes to avoid duplication with other legislation • Develop an education and outreach strategy

Adapted from: Watershed-based Source Protection Implementation Committee. (2004). *Watershed-based Source Protection: Implementation Committee Report to the Minister of the Environment* (PIBs 4938e). Toronto, Canada: Ontario Ministry of the Environment; pp. 51-54.

Although recommendations were made for each of the activities, the development of Farm Water Protection Plans (FWPP) to address risks associated with both large farms and farms in vulnerable areas may provide the most effective means of addressing potential threats to drinking water sources within agricultural operations.[15] The Pathogen Sub-Committee also suggested a number of alternative approaches to protecting source water from pathogens. A *Process-Based Approach* was highlighted as an option for managing risks from source to tap. The Sub-Committee determined that this multi-barrier approach would be best implemented through the development of Best Management Practices for manure pre-treatment established in concert with time-of-travel, disinfection, and monitoring regimes. Similarly, in his review of the abatement and transport of microorganisms in the subsurface environment, Rebellato (2004) suggests that management of processes preceding the introduction of pathogens into source water may be the most effective in preventing contamination. Conventional farm-level biosecurity programs are based on this approach to prevent the introduction and spread of infectious disease within livestock. Similarly, biosecurity may be applied within manure management practices to prevent the introduction of pathogens into source water.

The increasing focus placed on agricultural operations as a source of pathogenic contamination is the result of current trends in the livestock industry. Increases in the number of animals per facility, growth of production facilities, concentration of the livestock industry, increased geographic distance between animal production and feed production facilities, and increased concentration of manure (US EPA, 2002a) have been noted within North America. A review of livestock inventories from surveys conducted in Canada reveal that cattle and hogs comprise a significant percentage of animal husbandry practices in Ontario.[16] In 2000, there were an estimated 3.4 million hogs in Ontario producing, on average, the equivalent amount of sewage as the province's 10 million residents (Miller, 2000; p. 9). For the 1st quarter of 2006, Statistics Canada estimated that there were 2.1 million head of cattle and 3.6 millions head of hogs on farms in Ontario (Table 2.4).

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[15] The development of Farm Water Protection Plans was a recommendation originally made by Justice O'Connor in the Walkerton Commission of Inquiry, 2002.

[16] Surveys are conducted quarterly by Statistics Canada to determine the number of livestock animals on Canadian farms. Farms with less than $1000 in sales, institutional farms, community pastures, and farms on Indian reserves are excluded from the program which began in 1994 (Statistics Canada, 2005a; "Target Population" Section).

Table 2.4: Livestock Inventories in Canada, 2006

	Cattle[1] (as of January 1, 2006)	**Hogs**[2] (as of April 1, 2006)	**Poultry**[3] (as of 2005)
		1 000 head	
Canada	14 830	14 460	646 745
Atlantic	286	331	40 617
Quebec	1 405	4 150	166 985
Ontario	2 139	3 593	213 702
Manitoba	1 490	2 920	30 557
Saskatchewan	2 950	1 300	22 671
Alberta	5 900	2 000	55 042
British Columbia	660	166	105 375

1. Source: Statistics Canada. (2006b). *Hog Statistics* (vol. 5, no. 2; 23-010 XIE). Ottawa, Canada: Author; p. 6.
2. Source: Statistic Canada (2006c). *Cattle Statistics* (vol. 5, no. 1; 23-012-XTE). Ottawa, Canada: Author; p. 7.
3. Source: Statistics Canada. (2006d). *Poultry Statistics* (vol. 3, no. 1; 23-015-XIE). Ottawa, Canada: Author; p. 12.

Compared to national averages, Ontario farms account for 14, 25, and 33 % of cattle, hog, and poultry markets in Canada, respectively (Table 2.4). The number of livestock operations has decreased dramatically in the past 15 years, yet the number of animals has remained relatively unchanged (Ontario Ministry of Agriculture and Food, 2000a; para.1). Since 1988, inventories of hogs have risen by 9.61% in Ontario, while the national average has increased by 26.29% (Appendix 2.3). A similar trend has been observed in cattle inventories. Nationally, cattle inventories have increased by 28.88% since 1988, while in Ontario, stocks have decreased by 4.70% (Appendix 2.4).[17] The static number of livestock head is the result of the trend towards large-scale livestock operations commonly referred to as Intensive Livestock Operations (ILO's). In Ontario, large commercial livestock operations are defined as having more than 300 Nutrient Units (L. Macerollo, personal communication, June 19, 2006) which would translate to 300 beef cows, 1 800 finishing pigs, or 45 000 laying hens (Appendix 2.1).

[17] Historic poultry inventories by province are not available.

2.2.3 The Proposed *Clean Water Act*

In keeping with recommendations made in Part 2 of the Walkerton Commission of Inquiry, the proposed *Clean Water Act* focuses on the protection of hydrologic systems, methods for reducing water usage, and the restoration and enhancement of critical areas such as wetlands, riparian areas, and surface water. [18] The potential impacts of development and principles of sustainability are also considered as important factors to successfully protect source water.

Designed as enabling legislation, the proposed *Clean Water Act* allows for the development of regulations that will align with the intended purpose of protecting existing and future sources of drinking water. The Act also establishes Source Protection Authorities to enforce those regulations. Ultimately, the legislation is intended to "protect both the quality and quantity of municipal drinking water sources [and is] designed to promote voluntary initiatives and require mandatory action where needed" (Ontario Ministry of the Environment, 2006c; p. 1).[19] Due to an integrated planning and decision making process, watershed-based approaches have been recognized as the preferred means of policy development. By defining source protection areas in accordance with those already established by Conservation Authorities, the proposed Act recognizes that watershed-based approaches are the preferred means of policy development (Table 2.5).[20]

Conservation Authorities have presided over source water protection in the Province of Ontario for over 70 years.[21] The *Conservation Authorities Act* (1990) established a mandate to protect and manage natural resources through the implementation of flood control strategies, soil erosion prevention, and water quality monitoring programs. Conservation Authorities manage these natural resources based on an ecosystem unit, rather than a political unit (Conservation Ontario, 2003) thereby considering the dynamics of entire watersheds. Undoubtedly, the use of

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[18] The proposed *Clean Water Act* (Bill 43) was introduced in the Ontario Legislature on December 5th, 2005.
[19] Local municipalities may pass a council resolution to include drinking water systems other than municipally-owned residential systems in the source protection planning process (Ontario Ministry of the Environment, 2006c).
[20] Approximately 10% of Ontario's population resides in areas that are not managed by a conservation authority (Ontario Ministry of the Environment, 2005g; p. 1). The boundaries of source protection areas may be altered to expand the areas to include lands contributing to the source water in a defined watershed. A list of the municipalities affected by the alteration of the boundaries is provided in Appendix 2.4. Individual source protection areas could be grouped into source protection regions to coordinate planning and to allocate resources more efficiently. A list of the proposed source protection regions is provided in Appendix 2.5.
[21] Source water is raw, untreated water originating from surface bodies of water such as lakes and rivers, or from underground supplies.

watershed-based management regimes has been effective in protecting natural resources; however, they fail to address pollutants that originate from non-point sources (Deason *et al.*, 2001) and have only recently been incorporated into mandates directing the protection of drinking water.

Table 2.5: Roles and Responsibilities of Stakeholders for the Proposed *Clean Water Act*

Stakeholder	Roles and Responsibilities[1]
Conservation Authorities	• Facilitate the source protection planning process for the Source Protection Area • Provide support to municipalities in protecting drinking water • Gather information, develop risk assessments, organize consultations, train, and support municipal staff and integrate municipal strategies into larger watershed plans Source Protection Areas will be established as those areas over which a Conservation Authority already has jurisdiction pursuant to the *Conservation Authorities Act*. Conservation Authorities (CA) will act as the Source Protection Authority for that area. Areas outside of the authority of a CA may be designated by the Minster.
Municipalities	• Develop and implement risk management strategies for activities within their jurisdiction • Authority to require landowners to take action on drinking water threats
Committees	• Prepare Terms of Reference, assessment reports, and source protection plans
Landowners, industry, businesses, farmers, community groups, and the public	• Provide representation on planning committees and working groups • Participate in public consultation exercises • Individuals may be required to prepare and carry out risk management plans to address significant drinking water threats

1. Source: Ontario Ministry of the Environment. (2005a). *The proposed Clean Water Act: Roles and responsibilities* (PIBS 5381e). Toronto, Canada: Author; pp. 1-2.

Under the Act, source protection committees would initiate the source protection process by developing a Terms of Reference (ToR) to manage risk assessments and planning (Appendix 2.6). The ToR would serve as an action plan by identifying roles and responsibilities, addressing involvement of the community and affected landowners, businesses, and industry, developing the consultation process, and identifying a mechanism to resolve disputes (Ontario Ministry of the Environment, 2005d). Following the approval of the ToR, threats to the quality and quantity of drinking water sources would be identified. Both Conservation Authorities and municipalities will be responsible for mapping the drinking water sources that require protection, identifying those sources that are considered to be vulnerable and assess the drinking water threats in vulnerable areas.[22] The responsibility for identifying potential sources of contamination and assessing threats to wells and water intakes would rest with municipalities, while groundwater recharge areas and vulnerable aquifers would fall under Conservation Authorities (Ontario Ministry of the Environment, 2005c).[23] Using a science-based risk assessment, the threats identification exercise would prioritize threats as: (a) those that need immediate action, (b) those that need monitoring, and (c) those that do not require action (Ontario Ministry of the Environment, 2005d). Once all of the threats have been identified, the municipality would be required to undertake broad consultation to develop a source protection plan that identifies opportunities to reduce existing and future risks, the implementation strategy, and methodology for determining the progress of the plan. In areas where existing programs and activities do not adequately protect drinking water sources, site-specific measures will be necessary. Risk reduction may be accomplished through the use of by-laws, education programs, incentives, land use planning initiatives, partnerships, orders, and permits (Ontario Ministry of the Environment, 2005d). The consultation process would ensure transparency and lead to the development of plans that address local needs.

Municipalities may elect to take early action on significant threats prior to the development the source protection plan. The authority granted under the Act would allow municipalities to order businesses, farmers, and individual property owners to develop a risk management plan consisting of site-specific measures taken that would ensure that the activity does not pose a significant threat to source water (Ontario Ministry of the Environment, 2005d). The intended goal of the risk management plan is consistent with the Recommendation Number 13 made by O'Connor (2002) to develop individual water protection plans.[24] Following the approval of the source protection plan, any activity identified as a significant threat to drinking water that is currently operating, or proposing to operate, in a municipal wellhead protection area or surface water intake protection zone would be required to obtain a permit from the

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[22] For the purposes of the proposed *Clean Water Act*, vulnerable areas include: (a) well head protection areas established to prevent contamination of municipal drinking water supply wells, (b) surface water intake protection zones established to prevent contamination of municipal water supply intakes in lakes and rivers, (c) groundwater recharge areas where water leaches through porous soil or rock into aquifers, and (d) aquifers (Ontario Ministry of the Environment, 2005c).
[23] The Government of Ontario will provide $67.5 million towards scientific studies to identify and assess threats to drinking water sources (Ontario Ministry of the Environment, 2006d; p. 1).
[24] The risk management plan for agricultural operations is synonymous with Farm Water Protection Plans.

municipality based on the site-specific risk management plan (Ontario Ministry of the Environment, 2005e). In this respect, municipalities would have the discretion to specify site-specific conditions rather than resort to restricting practices for an entire geographical area. Through the source protection planning process, activities located in vulnerable areas can be limited or restricted provided the risk assessment demonstrates that the activity is a significant threat to source water (Ontario Ministry of the Environment, 2006c). Only if there is no existing provincial approval process to manage activities, could a permit be required under the proposed *Clean Water Act*.

While the task of identifying significant drinking water threats may be accomplished relatively quickly, developing and implementing source protection plans will likely be a lengthy and complicated process. Certainly, a number of threats to drinking water sources could be addressed through existing local programs. For instance, agricultural threats may be minimized through Environmental Farm Plans or other partnership activities at the local level (Ontario Ministry of the Environment, 2005b). However, the proposed *Clean Water Act* does not specify how the threats are to be addressed. The most vulnerable drinking water sources are likely to require additional action, especially where the risk of pathogenic loading is great. Given that manure has been identified as a major source of pathogens in Ontario, agricultural operations will be subject to risk management strategies. Risk management plans could play a role in protecting these vulnerable areas; however, a collection of recognized mitigative measures and management standards has not yet been established. To address this need, a review of manure treatment technologies should be conducted to determine the expected efficacy that mitigative measures could have in preventing pathogenic loading in source water.

2.3 Jurisdictional Review of Manure Management

A jurisdictional review was conducted to facilitate an improved understanding of how animal waste is currently regulated in order to protect source water. While the scope of this review was primarily based on the jurisdictional review of pathogen management conducted by the Watershed-based Technical Experts Committee (2004), additional jurisdictions were selected based on evidence of growth in commercial livestock operations. For additional information on legislation governing drinking water quality and source water protection, the reader is referred to Kelly (2005).

2.3.1 United States

In the United States, the National Pollutant Discharge Elimination System (NPDES) was created under the *Clean Water Act* (1977) to regulate the discharge of point source pollution into water. The NPDES permit identifies wastewater discharges to surface waters from the point source, establishes requirements to protect water quality, and allows operations to discharge pollutants provided the requirements to protect water quality are met (United States Environmental Protection Agency [US EPA], 2003c). Under the *Clean Water Act* (1977), Concentrated Animal Feeding Operations (CAFOs) are defined as point source dischargers.[25] In 2003, the National Pollutant Discharge Elimination Permit Regulation (40 CFR 122.23) and the Effluent Limitations Guidelines and Standards (40 CFR Part 412) for CAFOs were revised.[26] As such, CAFOs are required to obtain an operating permit under the NPDES to demonstrate that manure, litter, or wastewater from the production area of the CAFO are not being discharged to surface water. The permitting process applies to: (a) swine, (b) chicken and poultry, (c) dairy cow and heifer, (d) horse and sheep, and (d) beef cattle and veal calf CAFOs.[27] The minimum requirements for permitting processes are based on the Effluent Limitations Guidelines and Standards which may include technology-based effluent limitations or water quality-based effluent limitations, or both. Technology-based effluent limitations reflect the amount of pollutant reduction that can be achieved by applying pollution control technologies and/or

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[25] Section 208 of the *Clean Water Act* requires States to develop and implement area wide waste treatment management plans. The Act was revised in December, 2002 to include CAFOs as point source dischargers, *Clean Water Act* 33 U.S.C ss/1251 et seq. (1997), s. 502 (14).

[26] After the CAFO regulations were revised in 2003 a number of petitions for judicial review (originally filed in different circuit courts of appeal) were consolidated into one proceeding before the Second Circuit. The decision remanded provisions of the CAFO regulations. In response to the order issued by the Second Circuit Court of Appeals in *Waterkeeper Alliance et al. v. EPA, 399 F.3d 486 (2nd Cir. 2005),* the United States Environmental Protection Agency [US EPA] is currently seeking comment on a proposed rule that would revise several parts of National Pollutant Discharge Elimination System (NPDES) and Effluent Limitation Guidelines for concentrated animal feeding operations (US EPA, 2006b).

[27] Concentrated Animal Feeding Operations (CAFO) are categorized as either large or medium. The classification for a large CAFO is based on the number of animals located at the livestock facility, while a medium CAFO is based on a combination of the number of animals present at the livestock facility and a determination of how pollutants are discharged. Livestock operations can also be designated at a CAFO if it is determined to be a significant source of pollution. This determination can be reached regardless of the size of the operation (US EPA, 2003a). The permitting process generally applies to operations with 1, 000 or more animal units.

practices, while water quality-based effluent limitations reflect the existing conditions of the receiving waterbody (US EPA, 2003b). Additional requirements are at the discretion of state officials where the management of CAFO programs and permitting process is under the authority of the state. States may also have additional, non-federal permit requirements.

Although most States have been authorized to administer the federal NPDES program, the US EPA has the right to conduct inspections of livestock facilities to determine if operators comply with federal law. Livestock operations subject to the NPDES that are found to be discharging pollutants in the absence of a permit are in violation of the *Clean Water Act* (1997). In situations where livestock operators are found to be in violation of the *Clean Water Act* (1997), the US EPA will determine a course of action depending on the seriousness of the violation. Possible actions include: (a) issuing a notice of violation, (b) issuing an administrative order with or without a proposed administrative penalty, (c) initiating a civil suit, or (d) conducting a criminal investigation (US EPA, 2003a).

Voluntary technologies and management practices are also encouraged to complement and enhance the permitting process. The US EPA issued a guidance document in 2004 entitled Managing Manure Nutrients at Concentrated Animal Feeding Operations. This document was designed to introduce CAFO owners and operators to measures that would encourage water quality protection beyond the requirements set out in the NPDES permit. Few measures address opportunities for the reduction of pathogens. The use of digestion is noted as an option to help control some pathogens and incorporating manure into soil immediately following land application is suggested as a means to reduce the movement of pathogens to surface water. Operators are also encouraged to participate in the Voluntary Performance Standards Program. The program allows existing and new large beef, heifer, and dairy CAFOs and existing large swine, poultry, and veal CAFOs to discharge process wastewaters that have been treated by technologies that demonstrate equivalent or better rates of pollutant removal compared to the baseline requirements. In order to receive a discharge permit under this program, the treatment technology must be proven to effectively remove BOD_5, total nitrogen (ammonia, nitrite/nitrate, and organic nitrogen), total phosphorous, and total suspended solids. The selection of parameters is based on evidence of high concentrations in manure waste streams and potential impacts to surface water quality when left untreated (US EPA, 2004). While the removal of these pollutants can lead to the removal of other contaminants such as pathogens and metals, the program does not specifically target pathogens. If additional pollutants are present in the waste stream at concentrations high enough to impact surface water quality, then they may also be included at parameters in the permit (US EPA, 2004). Similar to permits issued outside of the Voluntary Performance Standards Program, if pollutant discharges from an alternative treatment system are greater than the concentrations specified in the NPDES permit, a CAFO may be subject to penalties.

A number of benefits may be realized through participation in the program. Greater flexibility in operation, increased good will of neighbours, reduced odour emissions, potentially lower costs, and improved environmental stewardship (US EPA, 2004) may be attractive benefits for CAFO operators. The US EPA is also considering other incentives that would strengthen participation in the program. As a result, the US EPA (2004) expects that as alternative technologies are developed, the voluntary measures employed by CAFOs will match or exceed the current requirements for treated effluent discharges. Furthermore, there may be opportunity to reduce or prevent the release of pollutants to other media, such as air.

2.3.2 Minnesota

The US EPA has authorized the State of Minnesota to administer the National Pollutant Discharge Elimination System (NPDES). The responsibility of administering that program falls under the Minnesota Pollution Control Agency. The collection, transportation, storage, processing, and disposal of animal manure is regulated by the Minnesota Pollution Control Agency through the Feedlot Program. The Feedlot Program focuses on ensuring that manure on a feedlot or manure in a storage area does not enter water bodies, and that manure application is timely and conducted in a manner that prevents nutrients and other contaminants from entering water (Minnesota Pollution Control Agency, 2005). The Feedlot Program applies to feedlots with 50 animal units or more, or 10 or more animal units on shore land (Minnesota Pollution Control Agency and Natural Resource Conservation Service, 2005). The Feedlot Rules contain requirements for registration and permitting, as well as, technical requirements for facility siting, expansion, construction, reporting, operation, and management. Manure treatment is not subject to the Feedlot rules. The Feedlot rules apply not only to those required to register or obtain a permit, but all feedlot owners and personnel responsible for the handling of manure are obligated to meet the technical requirements as well.

Although estimates suggest that the amount of manure produced by livestock in Minnesota is the equivalent of a human population of 50 million people (Minnesota Pollution Control Agency, 2005; p. 2) permits are required for very few livestock facilities in Minnesota. Of the 30, 704 registered feed lots in Minnesota, 990 are operating under NPDES permits (Minnesota Pollution Control Agency, 2005; p. 3). As such, there is a great need for well established and useful manure management programs. This realization has led to a permitting process that exceeds the minimum requirements established by the NPDES. In addition to manure management plans, proposed operations with over 1000 animal units, or over 500 animal units in a sensitive area, are required to complete an environmental assessment.[28] The environmental review process is conducted under the Minnesota Environmental Review Program. Although the environmental review applies to a small number of feedlots, it facilitates a better understanding of how the proposed project will affect environmental components such as air, water, and soil. The process further allows government agencies and citizens to participate in the decision-making process (Minnesota Pollution Control Agency and Natural Resources Conservation Service, 2005). Environmental Impact Statements are issued for proposed projects that are found to potentially cause significant environmental impacts. The Impact Statement describes the proposed project, alternatives to the undertaking, the environmental impacts of the project, and mitigative measures to address the impacts.

2.3.3 Wisconsin

Current water quality programs and legal requirements in the State of Wisconsin primarily address the use of pesticides and fertilizers with emphasis placed on the regulation of nutrients. Chapter NR 243 of the Wisconsin Administrative Code outlines State regulations concerning the storage and handling of manure. The rule creates the criteria used for issuing permits to CAFOs with 1, 000 or more animal units and specifies the procedures for addressing water quality risks imposed from animal feeding operations with less than 1, 000 animal units (Wisconsin Department of Natural Resources, 2002). Livestock operations with more than 1, 000

[28] Common sensitive areas include: (a) intermittent or perennial streams, (b) lakes and protected wetlands, (c) drainage ditches, (d) open tile intakes, (e) steeply sloping land, (f) road ditches, (g) frequently flooded soils, (h) highwater table soils, (i) high phosphorus soils, (j) wells and wellhead protection areas, (k) sinkholes, (l) coarse-textured soils, (m) shallow soils over bedrock, and (n) mines and quarries (Minnesota Pollution Control Agency and Natural Resources Conservation Service, 2005).

animal units are required to obtain a Wisconsin Pollutant Discharge Elimination System permit. As of April 7, 2006 a total of 146 Concentrated Animal Feeding Operations were permitted. The permits related to three beef, 125 dairy, 11 poultry, and 7 swine operations (Wisconsin Department of Natural Resources, 2006b; Permit Status Section).

In an attempt to reduce impacts to water quality caused by manure, the Wisconsin Department of Natural Resources recently revised manure management rules for the state's largest farms. The Natural Resources Board voted to adopt the NR 243 rule revisions on May 24, 2006 and the proposed revisions will undergo review by the Wisconsin Legislature (Wisconsin Department of Natural Resources, 2006a; para. 1). The revisions have been made to align with changes in the federal regulations. The Wisconsin Department of Natural Resources (2006a) proposes that revisions be made to:

1. Restrictions on applying solid and liquid manure on frozen or snow-covered ground.
2. Requirements for large CAFOs to have six months worth of liquid manure storage.
3. State-wide phosphorus-based nutrient management requirements.
4. Provisions for issuing general permits to groups of CAFOs in lieu of individual permits.
5. Adjustments to animal unit equivalency numbers.
6. Standard permit requirements for large CAFOs including mortality management, restrictions on chemical disposal in storage or containment facilities, stormwater controls, and development of an emergency response plan.
7. Manure and process wastewater application restrictions near waterbodies.
8. Allowances for temporary manure stacking in winter.
9. Provisions outlining circumstances under which a CAFO is not responsible for the disposal and land application of its manure and process wastewater.
10. Revised inspection, monitoring, and reporting requirements.
11. Permit requirements for small and medium CAFOs.

Wisconsin NR 151 (Run-off Management) also addresses potential risks to water quality from direct run-off from farm operations. The rule sets agricultural performance standards and prohibitions against direct run-off from for storage facilities, including constructed storage facilities, animal lots, and manure piles.[29] In addition, the Wisconsin Department of Agriculture, Trade, and Consumer Protection administers the ATCP 50 (Soil and Water Resource Management Program) that identifies conservation practices that farmers must follow, as well as the requirements for nutrient management plans (Wisconsin Department of Natural Resources and Wisconsin Department of Agriculture, Trade, and Consumer Protection, 2004). In a continuing effort to minimize opportunities for manure run-off and protect water resources, the Manure Management Task Force was established in 2005. The Wisconsin Department of Agriculture, Trade, and Consumer Protection, along with the Department of Natural Resources convene the Task Force. The Manure Management Task Force (2006) made several recommendations regarding the establishment of priorities for manure research, with the overall goal of facilitating a greater transfer of research into policy. Evaluating the effectiveness of Best Management Practices for the control of pathogens was identified as a research priority, as was understanding how to improve the economic viability of digesters and identifying opportunities for marketing compost. The Final Report was submitted to the Secretaries of the two agencies and is currently under review to develop a strategy to implement the recommendations made by the Task Force.

2.3.4 British Columbia

The British Columbia Ministry of Environment, Lands, and Parks administers the Code of Practice for Waste Management as part of BC Reg. 131/1992 (Agricultural Waste Control Regulation). The Regulation is made under the *Environmental Management Act* (2003) which is designed to protect air, water, and soil from pollution and allows a farmer to operate without a waste permit when storing and using manure according to the Code of Agricultural Practice for Waste Management.[30] The intent of the regulation is to prevent pollution associated with the collection, handling, use, and disposal of agricultural waste and dead livestock. The Code prescribes specifications on manure storage, handling and application, and applies to all agricultural operations in a manner similar to the protocols outlined in Ontario Regulations. The Code of Practice also specifies that the direct discharge of agricultural waste into surface or groundwater is prohibited and manure application to land is only permitted if the manure is being

[29] Wisconsin NR 151.015, s. 7.
[30] B.C. Reg. 131/1992, s. 2.

used as a fertilizer or soil conditioner.[31] The treatment of manure prior to land application to specifically address pathogenic removal is not addressed in this document.

2.3.5 Nova Scotia

The storage and handling or manure is not currently regulated under Canadian Federal or Provincial legislation. Operators responsible for manure entering water bodies may be subject to charges under the *Health Act* (1985) or the *Environment Act* (1994-95). For instance, the Nova Scotia Department of Environment and Labour requires that an environmental assessment be conducted on any storage facility holding more than 5, 000 m^3 of liquid or gaseous substances, which would include liquid manure.[32] As with many jurisdictions in Canada, the location of manure storage facilities and setback distances from neighbouring properties and streams is regulated under municipal by-laws.

For the majority of agricultural operations involving the storage and handling of manure, management is based on Best Management Practices that encourage voluntary action by farm operators. The Nova Scotia Department of Agriculture and Fisheries has developed a number of siting considerations and management practices for operations related to liquid and bedded housing systems, manure storage, and manure spreading in the hog production industry. The guidance material is designed to: (a) provide information to farmers on how to manage operations in an environmentally acceptable manner, (b) provide information to municipalities on management practices and siting considerations that can be incorporated into municipal by-laws, and (c) provide all stakeholders with guidelines to assess management practices and siting of hog farms (Nova Scotia Department of Agriculture and Fisheries, 2005).

General guidelines for manure management have also been development by the Ministry of Agriculture and Fisheries. In situations where specific by-laws do not exist, the Ministry recommends that the <u>Manure Management Guidelines, 2006</u> be followed (Crozier, 2004). The Guidelines apply to all livestock operations where the storage and handling of manure comprises a significant portion of routine farm operations.[33] The Guidelines refer to siting and

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[31] Code of Agricultural Practice for Waste Management, Part 5, s. 11 and 12.
[32] N.S. Reg. 44/2003, Schedule A, Class 1 Undertakings, s. 2, adopted under the *Environment Act*, S.N.S. 1994-95, c. 1.
[33] Intensive Livestock Operations are not currently defined at the provincial level in Nova Scotia. Instead, individual municipalities may set the definition (OMAFRA, 2005b).

construction of storage facilities, land application, odour management, and transportation of manure, but do not address manure treatment practices, nor do the Guidelines specifically address pathogens.

2.3.6 New Zealand

Regulatory control for water in New Zealand falls under the *Resource Management Act* (1991). The Act is administered by the Ministry of the Environment and controls all discharges to air, land, and water. The *Resource Management Act* (1991) is administered in each region by regional councils who have the authority to establish regional rules or require discharge consents. Resource consents are required when an activity will have an effect on the environment and is not permitted under a local authority's resource management plan (Government of New Zealand, 2005). There are five different types of resource consents that can be issued under the *Resource Management Act* (1991) and include: (a) land use, (b) subdivision consent, (c) coastal permit, (d) discharge permit, and (e) water permit.[34] (Government of New Zealand, 1991). Consequently, this legislation covers the use or spreading of manure, compost, or effluent onto land. At this time, the *Resource Management Act* (1991) does not contain specific regulations on the land application of nutrients, but there are a number of non-statutory guidelines that regional councils can use when setting resource consent conditions. Guidelines for the use of natural and physical resources are established under the *Resource Management Act* (1991) and include activities such as taking or discharging of water, discharges to air, and change of land use. Guidelines that are currently available address biosolids application, the use of sewage effluents, and standards related to composts.[35] According to in an e-mail communication on 31 January 2006, P. Prendergast (Principal Public Health Engineer, New Zealand Ministry of Health), noted that the lack of direct requirements in regulation to protect source waters used for drinking water has been a matter of concern for Ministry of Health. As a result, the Ministry for the Environment has now proposed a "National Environmental Standard" under the *Resource*

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[34] *Resource Management Act*, 1991 No.69, Part 6, s. 87.

[35] Available guidelines include: (a) Guidelines for the safe Application of Biosolids to Land in NZ (New Zealand Water and Waste Association, 2003), (b) New Zealand Guidelines for Utilisation of Sewage Effluent on Land (New Zealand Forest Research Institute, 2000), and (c) New Zealand Standard NZS 4454:2005- Composts, Soil Conditioners and Mulches (Standards New Zealand, 2005).

Management Act (1991) to protect drinking water sources. Following consultation with drinking water suppliers, local government, and the public, the proposed standard for human drinking water sources states:

1. Consents for drinking water catch areas shall only be granted if the proposed activity does not result in drinking water being non-potable or unwholesome following treatment.
2. Consent authorities will periodically assess the risks within drinking water catchments to ensure permitted and unregulated activities do not cause impacts beyond the performance of the affected treatment facilities.
3. Resource consents within drinking water catchments will have a condition that any unauthorized discharge (accidental spills and rainfall events) will need to be notified to the water supplier immediately.
4. Resource consents to take water for drinking will have a condition that requires appropriate action, including turning off the supply, if notified of events or activities that make the drinking water non-potable.

The proposed standard will require local governments to consider the quality of drinking water supplies when they decide on resource consents and require contingency plans to deal with high-risk events such as spills and accidents (New Zealand Ministry for the Environment, 2005a) and is expected to become a legally enforceable regulation (New Zealand Ministry for the Environment, 2005b).

2.3.7 Scotland

In Scotland, both legislation and guidance material are used to control water pollution generated by farm wastes and manures. The pollution of water is prohibited under the *Water Resources Act* (1991), while Regulation 324/1991 (Control of Pollution - Silage, Slurry, and Agricultural Fuel Oil) establishes the minimum standards for the construction of new manure storage facilities. These regulations may also apply to existing manure storage facilities should the Environment Agency determine that the nature and location of the structure present a risk for pollution (Scottish department for Environment, Food, and Rural Affairs [DEFRA], 2003b). The <u>Codes of Good Agricultural Practice for the Protection of Water, Air, and Soil</u> provide general advice to minimize pollution while protecting natural resources and maintaining the economic viability of the agriculture sector (DEFRA, 2003c). The <u>Water Code</u> (1998) acknowledges that there are a number of pollutants in agricultural operations that may pose a risk to water quality. The presence of microorganisms such as salmonellae, *Escherichia coli*, campylobacter, and *Cryptosporidium parvum* in animal slurry is recognized as a potential risk to human and livestock health. Given that surface or groundwater can become polluted with animal wastes, the Ministry of Agriculture, Fisheries, and Food (1998) recommends the use of a Manure Management Plan; a guideline document designed to assist operators with the development of a site-specific plan for spreading livestock slurries, manures, and organic wastes on land. The requirements for the completion of the Plan are similar to those outlined for nutrient management under Ontario Regulation 267/03. Scotland's Manure Management Plan is based on five steps to ensure that the risk of pathogen transfer from animal waste to water is minimized and include:

1. Calculating the area of crops and grass available for spreading livestock manures.
2. Identifying areas where livestock manures should not be spread under certain conditions or where rates should be restricted.
3. Calculating the minimum area of land needed for spreading livestock manures.
4. Guidelines for spreading sewage sludge or other organic wastes.
5. Assessing whether extra storage is needed for slurry and dirty water.

On farms where *C. parvum* has been identified, the Code further recommends that slurries are stored for as long a possible prior to spreading and that farmyard manure should be stored for at least two months before spreading (Scottish Ministry of Agriculture, Fisheries, and Food, 1998). The treatment of manure is briefly addressed within the Code of Good Agricultural Practice for the Protection of Water. Anaerobic digestion and aerobic treatment are recommended, but address the potential for reducing nuisances such as odour. The treatment of manure prior to land application to specifically address pathogenic removal is not addressed in this document.

Kelly (2005) conducted a review of the main legislative documents governing source water protection in Scotland. The *Cryptosporidium* (Scottish Water) Directions 2003, requires Scottish Water to monitor raw water sources for the presence of *Cryptosporidium* and to ensure that treatment plants remove the pathogen in an efficient and effective manner (Kelly, 2005).[36] The Directive requires that water authorities implement the recommendations outlined in the

[36] Scottish water is the publicly owned water supplier in Scotland.

Third Report of the Group of Experts on *Cryptosporidium* in Water Supplies. Not surprisingly, the recommendations include increasing the promotion of the Codes of Good Agricultural Practice for the storage and disposal of animal wastes (Boucher, 1998). The Directive also requires that an assessment of the risks to major surface and ground water supply systems from *Cryptosporidium* be conducted. The risk assessment must consider farming practices that occur over the course of an entire year, accounting for seasonal variations in wild animal and bird populations as well. Among the factors that are included in the risk assessment are agricultural practices. Both agricultural practices such as slurry spraying on agricultural lands, and the presence of animals in catchment areas pose a high risk of *Cryptosporidium* contamination. And although there is a risk of manure entering source water supplies after episodes of high rainfall events, the risk of contamination may be higher if animals have direct access to the water (Scottish Water, 2003b). As such, both of these factors are considered in the risk assessment. Upon completion of the risk assessment, Scottish Water is required to submit a report to the Scottish Ministers (Scottish Water, 2003b) and outline mitigative measures to be implemented for those areas that are determined to be high-risk (Scottish Water, 2003a). While the protection of source water supplies is being conducted, the current regulatory framework in Scotland does not address the prevention of pathogenic loadings.

2.4 Summary

Although source water protection is considered to be the first of five barriers for drinking water protection, it has not been adequately addressed in the current legislative framework in Ontario. Human illness and death caused by waterborne pathogens can be avoided by applying the appropriate level of protection in those areas where land use activities contribute to the contamination of source water. Given the risk to human health, there continues to be a need to further develop source water protection legislation. Maintaining the quality of surface and ground water supplies is especially important in agricultural areas where non-point sources of pollution are difficult to manage. While the *Nutrient Management Act* took great strides to initiate source protection for nutrients, the approach taken has failed to target the potential impacts of pathogenic contamination of surface and ground water supplies. Similarly, Best Management Practices have provided little protection against impacts on source water quality given a lack of scientifically supported recommendations. Furthermore, methods to prevent pathogenic contamination of source water in other jurisdictions are not developed and do not directly address the need for pathogen reductions prior to application. Given the trend towards the commercialization of livestock operations, many jurisdictions have recently made (or are currently making) revisions to policies and practices governing the storage and handling of manure. Requirements for conducting environmental and risk assessments and obtaining operating permits are also becoming increasingly common for large livestock operations, or operations that are located in areas that are vulnerable to water quality impacts.

Given that the microbiological quality of water is considered to be one of the most important factors when assessing water quality, there is an apparent need for a legislative framework supported by regulations that outline systematic methods to prevent pathogenic loadings in source water. One way to further ensure safe supplies of drinking water and to reduce operating costs is to prevent the introduction of pathogenic contaminants at the source. Mitigative measures, such as pathogen inactivation technologies for manure, have the potential to minimize and prevent pathogenic loadings in source water. By including measures to prevent pathogenic loadings into source water supplies, the reliance on treatment and response barriers could also be reduced. This approach is not intended to be a substitute for other levels of protection, but rather enhance the effectiveness of the first barrier in the multi-barrier approach and minimize the risks to source water quality. Given that the proposed *Clean Water Act* intends to characterize risks in watersheds from agricultural practices, the mechanism for responding to land use activities that contribute to the contamination of source water must work proactively. As such, a review of the efficacy of manure treatment technologies requires further investigation.

CHAPTER THREE: A NEW ROLE FOR BIOSECURITY

3.1 Biosecurity – A Defined Role in Agriculture

To a large extent, the implementation of biosecurity programs has been limited to livestock operations. The purpose of biosecurity programs among these operations is to control and eradicate disease in livestock in order to protect against economic loss. Since disease prevention is less expensive than treatment, biosecurity programs are based on proactive measures (Morris, 1995). Figure 3.1 illustrates this proactive approach through the use of multiple barriers. The most accepted framework for biosecurity involves preventing the entry of pathogens onto farms, preventing the spread of pathogens among animals, and preventing the transport of pathogens to other farms and animal products. As such, biosecurity may be best defined as "the intentional avoidance of disease through a planned program of risk reduction" (Kreager, 1995; p. 110).

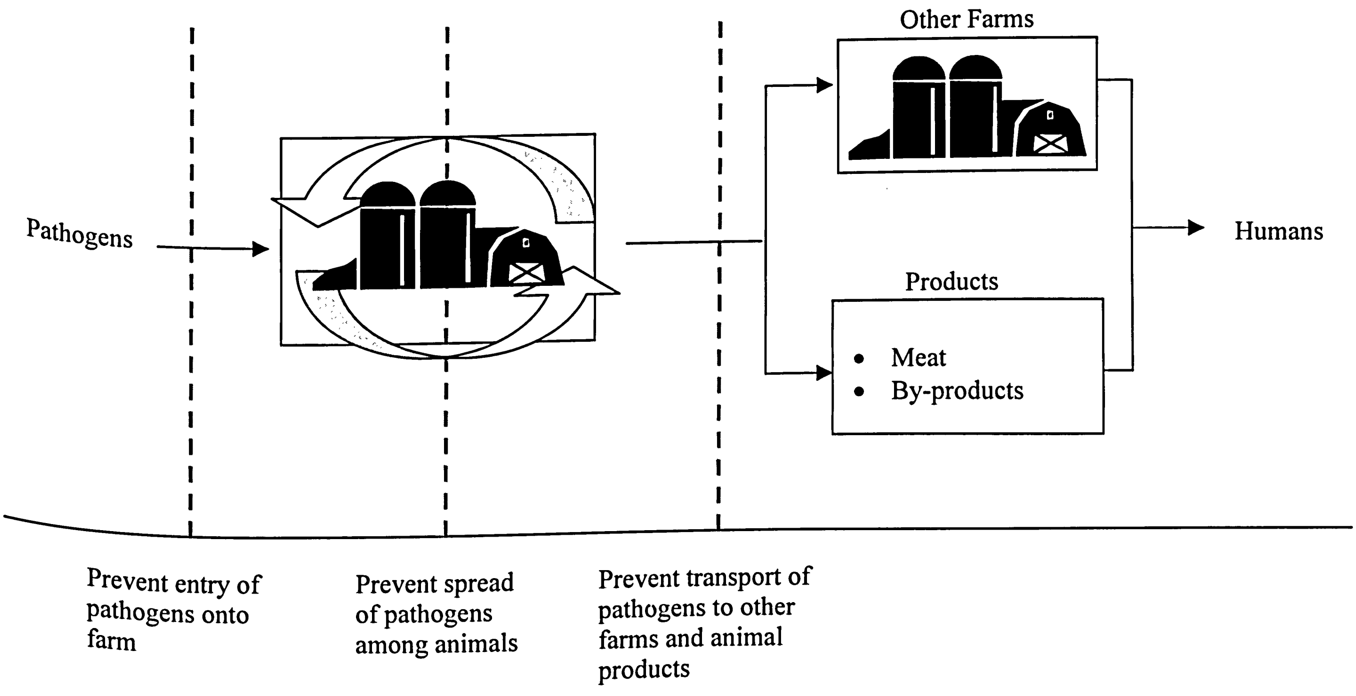

Figure 3.1: Conventional Farm-Level Biosecurity

The development of a biosecurity program is based on variations in the anticipated level of protection to be provided. Shane (1996) suggests that within agricultural operations biosecurity can be practiced at conceptual, structural, and operational levels. Each level influences both the cost and efficacy of the entire program. Conceptual biosecurity focuses on facility siting. For instance, proximity to other farms and public roads can influence where a facility is located and can impact the transmission of pathogens. Decisions made at this level directly impact subsequent levels of biosecurity and can not be easily altered. Structural biosecurity considers the most appropriate location for operational activities within a facility. Farm layout, location of fencing, and drainage systems fall under this level of biosecurity. Lastly, operational biosecurity is comprised of the routine procedures and management protocols used in day-to-day operations. Compared to the conceptual and structural levels of biosecurity, modifications to measures conducted at the operational level can be made quickly and easily (Shane, 1996). Like many management systems, processes must be continually monitored and periodically reviewed to determine their effectiveness. The use of contingency planning allows operational biosecurity to be strengthened within a matter of hours; while at the structural level, improvements may take months (Shane, 1996).

The poultry industry is considered to be one of the most progressive in terms of biosecurity program development. The industry's success is likely attributed to the strong emphasis placed on operational level biosecurity. For instance, Gibbens *et al.* (2001) examined the value of commonly used operational biosecurity procedures to prevent thermophilic *Campylobacter* infection in broiler chickens (Table 3.1).

Table 3.1 Operational Biosecurity Measures in Livestock Operations for Disease Prevention and Eradication[1]

Preparation of Facilities	Standard Hygiene Protocols
• Dust removal • Washing and disinfection of internal surfaces • Drying period between washing and disinfection of internal surfaces • Disposal or wash/disinfect equipment • Disinfection of water system • Disinfection of concrete areas surrounding the facility	• Boot dips • Dedicated boots and overalls • Hand sanitizer • Dedicated clean area

Generated from: Gibbens, J.C., Pascoe, S.J.S., Evans, S.J., Davies, R.H., and Sayers, A.R. (2001). A trial of biosecurity as a means to control *Campylobacter* infection of broiler chickens. *Preventive Veterinary Medicine,* 48:85-99; p. 87.

1. These activities are proposed for the control of *Campylobacter* infection in chickens.

After 42 days of age the prevalence of *Campylobacter* infection was reduced by over 50% in flocks managed with a biosecurity program compared to the control (Gibbens *et al.*, 2001; p. 85). In fact, control flocks were nine times more likely to be infected at 42 days of age than those flocks managed with a biosecurity program (Gibben *et al.*, 2001; p. 89).

In commercial livestock operations, conducting a risk assessment for infection is considered to be the most subjective part in the development of a biosecurity program (Shane, 1996). Risk assessments must consider all potential sources and routes of exposure for the contaminant(s) of concern. For example, in a pork production unit, introducing infected animals is the easiest way to transmit pathogens into a herd (Amass and Clark, 1999). Other potential sources of pathogens include aerosol transmission, rodents, insects, birds, domestic and feral animals, feed, and vehicles. Admittedly, a lack of controlled investigations and evidence can neither confirm nor negate that these sources are able to transmit pathogens. Nevertheless, these sources must be addressed should future research determine otherwise and should be addressed as part of biosecurity program development at large.

3.2 Jurisdictional Review of Biosecurity Programs

Differences in the definition of biosecurity are based on how and where biosecurity is applied. For instance, the establishment of a biosecurity program among national, regional, and local regulatory levels differs based on varying degrees of interest and expected outcomes (O'Bryen and Lee, 2003). A jurisdictional review was conducted to facilitate an improved understanding of how biosecurity is currently defined and practiced. While the scope of this review was primarily based on the Source Water Protection and Pathogens Jurisdiction Review (2004), additional jurisdictions were selected based on evidence of growth in commercial livestock operations, or omitted due to a lack of available information.

3.2.1 United States of America

The United States Environmental Protection Agency ([US EPA] 2006a; para. 1) defines biosecurity as "the protection of agricultural animals from any type of infectious agent – viral, bacterial, fungal, or parasitic." In response to nation-wide concerns over the spread of animal disease, routine biosecurity procedures for EPA personnel visiting farms, ranches, slaughterhouses, and other facilities with livestock and poultry were finalized in 2001. Separate emergency procedures apply in serious disease outbreaks. Emergency procedures are co-ordinated with the United States Department of Agriculture (USDA) Animal Health and Plant Health Inspection Service and local emergency control authorities (US EPA, 2006a).

3.2.2 Minnesota

In the state of Minnesota, biosecurity is defined as "the protection of animals and humans from infectious disease. Biosecurity measures can prevent the introduction of new diseases into an operation and prevent the movement of infectious diseases within the operation" (Minnesota Board of Animal Health, 2006; para. 1). The implementation of biosecurity measures in agricultural operations is encouraged by both the Minnesota Board of Animal Health and the Department of Agriculture. A one-page fact sheet is available to producers with tips on how to safeguard animal health. General guidance on minimizing the introduction of pathogens via vehicles, animals, personnel, and visitors is provided, but practices are not regulated.

3.2.3 Ontario

The Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) does not formally define biosecurity for provincial livestock applications, although the current framework for the industry is based on preventing the introduction and spread of disease among animals. Guidance material currently available from OMAFRA is directed towards livestock owners and industry personnel for preventing disease introduction onto farms and to control the spread of disease among animals within a farm. Sanitation and disinfection management strategies are strongly encouraged to prevent the spread of pathogens. A number of Best Management Practices provide guidance on the disposal of dead animals, management of manure, and the control of vectors. Anderson (2005) notes that an effective biosecurity program should consider measures that provide for adequate sanitation such as manure management in order to prevent the spread of disease. Manure systems that avert environmental contamination and treating or storing manure to achieve pathogenic destruction are recommended to ensure herd health (Anderson, 2005) but specific direction on the implementation of these practices is not provided. For some operators, sanitation may be regulated by law. For instance, the *Milk Act* (1990) regulates the production and quality of milk and milk products in Ontario.[37] Ontario Regulation 761/03 (General) specifies that all parts of the premises, with the exception of loafing-type stables, are to be kept clean and free from the accumulation of manure and that manure is to be stored in a manner that prevents access by animals and minimizes run-off and the breeding of flies.[38]

3.2.4 British Columbia

The Food Safety and Quality Branch of the British Columbia Department of Agriculture and Lands provide advice on farm biosecurity. Guidelines were published in 2005 outlining measures for Department staff on preventing the spread of plant pests and diseases from farm to farm during field inspections. A Biosecurity Committee has also been formed under the British Columbia Poultry Association. The Poultry Association (2005; p. A1.1) defines biosecurity as "a series of steps taken to prevent the introduction and spread of an infectious agent onto and between farms." While this definition could be loosely interpreted, emphasis is placed on animal disease and was created in response to the Avian Influenza outbreak in the Fraser Valley in 2004. Under the direction of the Biosecurity Committee a number of protocols were developed through a collaborative effort by producers, veterinarians and industry representatives.

3.2.5 New Zealand

In New Zealand, the *Biosecurity Act* came into force on October 1, 1993, although a generally accepted definition of Biosecurity was not developed until a decade later. The New Zealand Biosecurity Council (2003; p. 5) defines biosecurity as "the exclusion, eradication, or effective management of risks posed by pests and diseases to the economy, environment and human health." The *Biosecurity Act* is considered to be the world's first law that was designed to specifically support the protection of biological systems from the harmful effects of exotic pests and diseases introduced into New Zealand (Hellström, 2003). A number of regulations have been made pursuant to the Act, many of which impose levies on operators for activities that fall within the scope of the country's Biosecurity program. For instance, shipping practices are subject to levies to help fund programs to prevent the introduction of gypsy moths into the country. Other

[37] *Milk Act*, R.S.O. 1990, Chapter M. 12, s. 2 (b) and (c).
[38] R.R.O. 1990, Reg. 761, s. 11 (1) and (2).

regulations provide for disease tracking through animal identification systems, regional pest management strategies, and restrictions on the use of ruminant protein in animal feed.

Due to increasing pressures from trade and tourism, a review of New Zealand's biosecurity program was conducted in 2003 to prioritize changes in the program (New Zealand Biosecurity Council, 2003).[39] Fifty-seven recommendations were made on various aspects of the program with focus placed on improving stakeholder relationships, increasing emphasis on science-based decision making, narrowing gaps in program delivery, ensuring consistent funding mechanisms, and consolidating the program's accountability framework. Immediate action was taken to address inconsistencies in the program's accountability framework and shortly there after, the New Zealand Ministry of Agriculture and Forestry (MAF) became accountable for the overall management of the country's biosecurity system. Policy and operations are based on protecting the industry from foot and mouth and other diseases by placing much of the focus on border control.[40] Responsibilities within the MAF are divided among the Biosecurity Strategic Unit, Biosecurity New Zealand and MAF Quarantine Service.[41] The Biosecurity Council (2003) also acknowledged that as the scope of biosecurity continues to expand, it is becoming increasingly difficult to ensure the consistent delivery of the program. Although the biosecurity program was originally developed to protect primary production, additional interests in protecting flora, fauna, and human health are also being considered as part of the program's mandate (Biosecurity Council, 2003) although the protection of source water against pathogenic contamination is not specifically addressed.

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[39] New Zealand is particularly vulnerable to the threat of new pests and diseases given their dependence on agriculture, horticulture, forestry, and marine industries (New Zealand Ministry of Agriculture and Forestry [MAF], 2005).

[40] Foot and mouth disease is a severe, highly communicable viral disease of cattle and swine. The disease is characterized by fever and blister-like sores on the tongue and lips, in the mouth, on the teats and between the hooves. Many affected animals recover, but the disease leaves them weakened and debilitated (Canadian Food Inspection Agency, 2005; para. 1).

[41] The *Biosecurity Strategic Unit* supports the governance of New Zealand's biosecurity system. The *MAF Quarantine Service* manages biosecurity risks at ports, airports, and related facilities. *Biosecurity New Zealand* is responsible for (a) risk analysis, operating standards, and monitoring; (b) surveillance, incursion response, and pest management; (c) investigation and diagnostics; (d) compliance and enforcement; (e) policy and (f) animal welfare (MAF, 2005).

3.2.6 Scotland

In the context of working or coming into contact with farm animals, biosecurity has been defined by the Scottish Department for Environment, Food and Rural Affairs ([DEFRA] 2003a; p. 3) as "the prevention of disease causing agents entering or leaving any place where farm animals are present (or have been present recently) [and] involves a number of measures and protocols designed to prevent disease causing agents from entering or leaving a property and being spread." [42] In an effort to promote the continued use of biosecurity measures, DEFRA has developed a national biosecurity campaign. While the campaign stresses the importance of preventing the spread of highly contagious diseases, such as Foot and Mouth disease, preventing the spread of *Salmonella* and *E. coli* O157 is also encouraged (DEFRA, 2005). The awareness campaign has also been designed to ensure that operators are aware of their legal obligations to prevent the spread of diseases at markets and during the transportation of livestock. Under the *Animal Health Act* (2002) and the Animal Gatherings Order (2004), biosecurity measures such as foot-dips and hand washing facilities must be provided at markets where animals are bought and sold. Similarly, under the Transport of Animals (Cleansing and Disinfection) Order (2003), vehicles used to transport livestock must be cleaned and disinfected appropriately.

In accordance with the *Animal Health Act* (2002), a Biosecurity Guidance document outlines legal requirements and good practice measures.[43] The guidance focuses on precautions to be taken when entering or leaving any premises with farm animals in (a) the absence of an outbreak of exotic notifiable disease, (b) after confirmation of an outbreak of exotic notifiable disease, and (c) premises under specific animal disease restrictions (DEFRA, 2003a). It focuses specifically on minimizing the spread of disease through contact with clothing, footwear, vehicles, and machinery and does not refer to biosecurity in the context of preventing pathogenic loadings to water.

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[42] A causative agent includes any virus, bacterium and any other organism or infectious substance which may cause or transmit disease (*Animal Health Act*, 2002, s. 16, 6A Biosecurity Guidance, (8)).

[43] Under the *Animal Health Act*, 2002, Section 16, 6A Biosecurity Guidance (1) the Secretary of State must prepare guidance on the appropriate biosecurity measures to be taken in relation to Foot and Mouth Disease and any other disease specified by the Secretary of State. Section 16, 6B Biosecurity Compliance, 5 a – d, also requires periodic reviews and if necessary, revisions to the guidance material. Compliance is required by (a) any person having functions under the Act, (b) any person who is the owner or occupier of premises on which animals are kept (c) any person who is in charge of animals, and (d) any person who is under the direction of a person mentioned in paragraphs a) to c).

3.3 Summary

Presently, there is little information available on farm-level biosecurity practices. Only recently as outbreaks of disease occur, have programs been developed to address threats to animal health. Although a number of industry organizations have developed biosecurity protocols, governing bodies largely rely on general guidance and not regulated practice. In comparison, jurisdictions concerned with the introduction of invasive alien species and modified organisms have had long-standing biosecurity programs. As these programs strengthen and the potential for other ecological impacts are recognized, the scope of biosecurity has expanded. Despite this broadening scope, biosecurity programs have not yet been directed at pathogenic reductions on farms to reduce input into source water.

CHAPTER FOUR: NOTIFIABLE DISEASES

4.1 Manure-Related Pathogenic Responses

As water contaminants, microorganisms can reach human receptors through a variety of exposure pathways. The most common exposure pathways include the swallowing of contaminated water and eating of uncooked food that may have been irrigated, washed, or come into contact with contaminated water (National Center for Infectious Disease Control, 2004; Bicudo and Goyal, 2003). The presence of bacteria, protozoa, and viruses in water supplies commonly lead to pathogenic responses in humans (Atlas, 1997). Waterborne pathogens are the primary concern in drinking water. These pathogens are enteric in nature; that is they are shed from infected humans and animals through feces (Watershed-Based Technical Experts Committee, 2004). While the entry of human feces into source water is controlled by wastewater treatment, animal feces are not as thoroughly treated and managed. In agricultural operations, soils are often supplemented with nutrient-rich amendments, such as manures, to help facilitate plant growth. Contamination largely results from run-off following land application or accidental releases from manure containment facilities to surface or ground water supplies (Smith and Perdek, 2004; Olson, 2001). The improper storage and handling of manure is also linked to excessive algal growth, as well as aesthetic issues such as increased odour and die-off of flora and fauna (Environment Canada, 2001). As a result, both human and ecosystem health are negatively impacted.

The risk of contamination is not limited by spatial or economic scales. Smith and Perdek (2004) compiled a summary of manure-related human epidemics over the last 15 years, including four cases in North America where death or illness resulted from agricultural run-off (Table 4.1).

Table 4.1: Manure Related Human Epidemics in North America

Location	Year	Pathogen	Impact	Suspected Source
Walkerton, Ontario, Canada	2000	*E. coli* O157: H7 and *Campylobacter* spp.	2300 cases, 6 deaths	Run-off from farm fields entering town's water supply
Carrollton, GA	1989	*Cryptosporidium parvum*	13 000 cases	Manure run-off
Milwaukee, WI	1993	*Cryptosporidium parvum*	100 000 cases, 87 deaths	Animal manure and/or human excrement
Cabool, MO	1990	*E. coli* O157: H7	243 cases, 4 deaths	Water line breaks in farm community

Source: Smith, J.E. Jr., and Perdek, J.M. (2004). Assessment and Management of Watershed Microbial Contaminants. *Critical Reviews in Environmental Science and Technology,* 34(2): 109-140; p. 118.

Their review further illustrates that significant impacts have been experienced globally, with outbreaks occurring in the United Kingdom and parts of Asia (Appendix 4.1). The pathogens *Escherichia coli* O157: H7 and *Cryptosporidium parvum* have been responsible for the majority of manure-related human epidemics. The most severe outbreak occurred in Milwaukee, Wisconsin in 1993 when 87 deaths and 100 000 cases of illness occurred after drinking water supplies were contaminated with *Cryptosporidium parvum.* Other notable outbreaks have been attributed to *Campylobacter* species.

4.2 Waterborne Disease Prevalence in Ontario

Rates of disease are monitored by the Public Health Agency of Canada through the Centre for Infectious Disease Control.[44] Diseases that are considered to be of significant importance to public health are surveyed nationally and classified as *notifiable* (Public Health Agency of Canada [PHAC], 2003a). Notifiable diseases are agreed upon through the Advisory Committee on Epidemiology which is comprised of both provincial and federal health authorities.[45] Diseases currently under surveillance in Canada include Verotoxigenic *E. coli*

[44] Disease rates are the portion of a group affected over a period of time. For notifiable diseases the period of time is one calendar year (Public Health Agency of Canada [PHAC], 2003b).
[45] The Advisory Committee on Epidemiology meets twice annually at which time notifiable diseases may be added or deleted (PHAC, 2003a). The national surveillance list was updated in 2000. The current list of notifiable diseases can be found in Appendix 4.2.

infection, Campylobacteriosis, Giardiasis, Salmonellosis and Cryptosporidiosis. The Public Health Agency of Canada does not distinguish waterborne diseases from all enteric pathogens. Surveillance databases generally do not contain information on routes of exposure (food, water, person-to-person). Furthermore, pathogen sources are rarely identified unless a disease outbreak has occurred. *Cryptosporidium* and *Giardia* are generally waterborne pathogens and are often used as surrogate indicators of disease, but are limited in their application (PHAC, electronic communication, December 15, 2005). A general description of diseases currently under surveillance is provided in Sections 4.2 and 4.3.

Table 4.2: Average Notifiable Waterborne Disease Incidence in Canada, 1988-2000

	Ve rotoxigenic *E. coli* infection	Campylobacteriosis	Giardiasis	Salmonellosis	Cryptosporidiosis[1]
	Rate of Disease/ 100 000 People[2] (SD)				
Canada	5.48 (1.54)	45.18 (4.02)	25.12 (6.92)	26.33 (7.97)	2.62
Newfoundland	1.15 (0.67)	20.49 (6.57)	13.19 (8.87)	21.62 (12.71)	0.00
Prince Edward Island	9.33 (3.87)	50.24 (19.71)	8.78 (4.80)	27.43 (13.33)	0.00
Nova Scotia	3.39 (2.14)	27.27 (6.37)	12.27 (2.79)	20.00 (7.26)	0.64
New Brunswick	3.30 (2.23)	38.24 (9.78)	15.54 (2.71)	28.53 (12.75)	2.65
Quebec	5.48 (1.34)	34.33 (7.02)	11.10 (1.91)	19.88 (5.14)	-
Ontario	5.06 (2.53)	53.97 (9.47)	27.26 (8.55)	31.52 (12.28)	1.86
Manitoba	7.24 (2.71)	21.17 (2.50)	14.07 (5.89)	18.78 (3.99)	5.76
Saskatchewan	4.11 (1.04)	25.66 (2.81)	44.54 (21.07)	26.69 (10.56)	3.13
Alberta	7.55 (2.88)	38.70 (4.90)	35.15 (17.12)	29.00 (6.63)	3.19
British Columbia	5.18 (1.80)	65.00 (8.89)	42.11 (4.69)	25.59 (8.31)	4.16
Yukon	2.55 (4.60)	23.01 (9.41)	97.62 (39.02)	25.83 (11.77)	16.34
Northwest Territories	34.23 (95.36)	20.03 (7.66)	56.27 (29.71)	41.58 (15.93)	0.00
Nunavut[3]	134.53	0.00	21.82	65.45	3.64

Generated from: Public Health Agency of Canada. (2005). *Notifiable Disease Incidence by Year, 1988-2000.*

1. The surveillance of Cryptosporidiosis in Canada commenced in 2000. Standard Deviation can not be calculated using one datum.
2. Rates of disease are determined for a period of one calendar year.
3. Data for Nunavut is only available from one calendar year.

Average rates of disease from 1988-2000 are presented in Table 4.2. Among those diseases currently under surveillance, Campylobacteriosis has the highest incidence in both Canada and within the Province of Ontario. The average disease incidence for Campylobacteriosis, Giardiasis and Salmonellosis were 19.46, 8.52 and 19.71% higher in Ontario, respectively, compared to the national surveillance data (Table 4.2). In comparison, the average disease incidence for Verotoxigenic *E. coli* infection and Cryptosporidiosis was 7.66 and 29.01% lower in Ontario, respectively, compared to the national surveillance data.

The Yukon, Nunavut, and the Northwest Territories reported disease rates that were alarmingly higher than the Canadian average for Verotoxigenic *E. coli* infection, Giardiasis, Salmonellosis, and Cryptosporidiosis. The average incidence of Verotoxigenic *E. coli* infection was 6 and 24 times higher in the Northwest Territories and Nunavut, respectively, compared to national values.[46] Similarly, the average incidence of Salmonellosis in the Northwest Territories and Nunavut were 57.92 and 148.6% higher. Rates of Giardiasis were also considerably higher than national values for a number of provinces and territories. The average incidence of Giardiasis was 288% higher in the Yukon, 124% higher in the Northwest Territories, 77.31% higher in Saskatchewan, and 67.60% higher in British Columbia compared to national values. Surprisingly, British Columbia also had significantly higher rates of Campylobacteriosis and Cryptosporidiosis that are 43.99 and 58.79% over the Canadian average, respectively.

Over time, the rates of Verotoxigenic *E. coli* and Campylobacteriosis have been steady. The first positive case of Verotoxigenic *E. coli* infection in Canada was not confirmed until 1990. While the national rate of Verotoxigenic *E. coli* infection has declined steadily for 10 years, the disease rate nearly doubled in 2000. This increase is due in large part to an outbreak of Verotoxigenic *E. coli* in Ontario.[47] This outbreak increased the provincial rate by nearly 4 times compared to 1999 (Figure 4.1). In contrast, rates of Campylobacteriosis have declined only marginally over time. In Ontario, the disease incidence has decreased by 26.60% since 1988,

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[46] Nunavut recently became a territory when the Northwest Territories was divided in April of 1999 (Indian and Northern Affairs Canada, 2003; para. 1). As such, surveillance data for Nunavut are only available for the year 2000. The change in governance may have lead to poorly maintained and operated drinking water treatment and distribution systems, subsequently leading to higher rates of disease. The rates of disease for the Northwest Territories prior to dissolution have, however, historically been high suggesting that other factors, such as prolonged pathogen survival in frozen soil and water, may be responsible for the high rates of disease.
[47] The outbreak was attributed to the introduction of the pathogen into a municipal drinking water distribution system.

while the national average decreased by 7.11%. In 1994, the rate peaked in both Ontario and across the country. Similarly, rates of Giardiasis and Salmonellosis have declined, but by a significantly higher margin. The rate of Giardiasis has declined by 51.90% and the rate of Salmonellosis has declined by 67.34% in Ontario since 1998 (Figure 4.1).

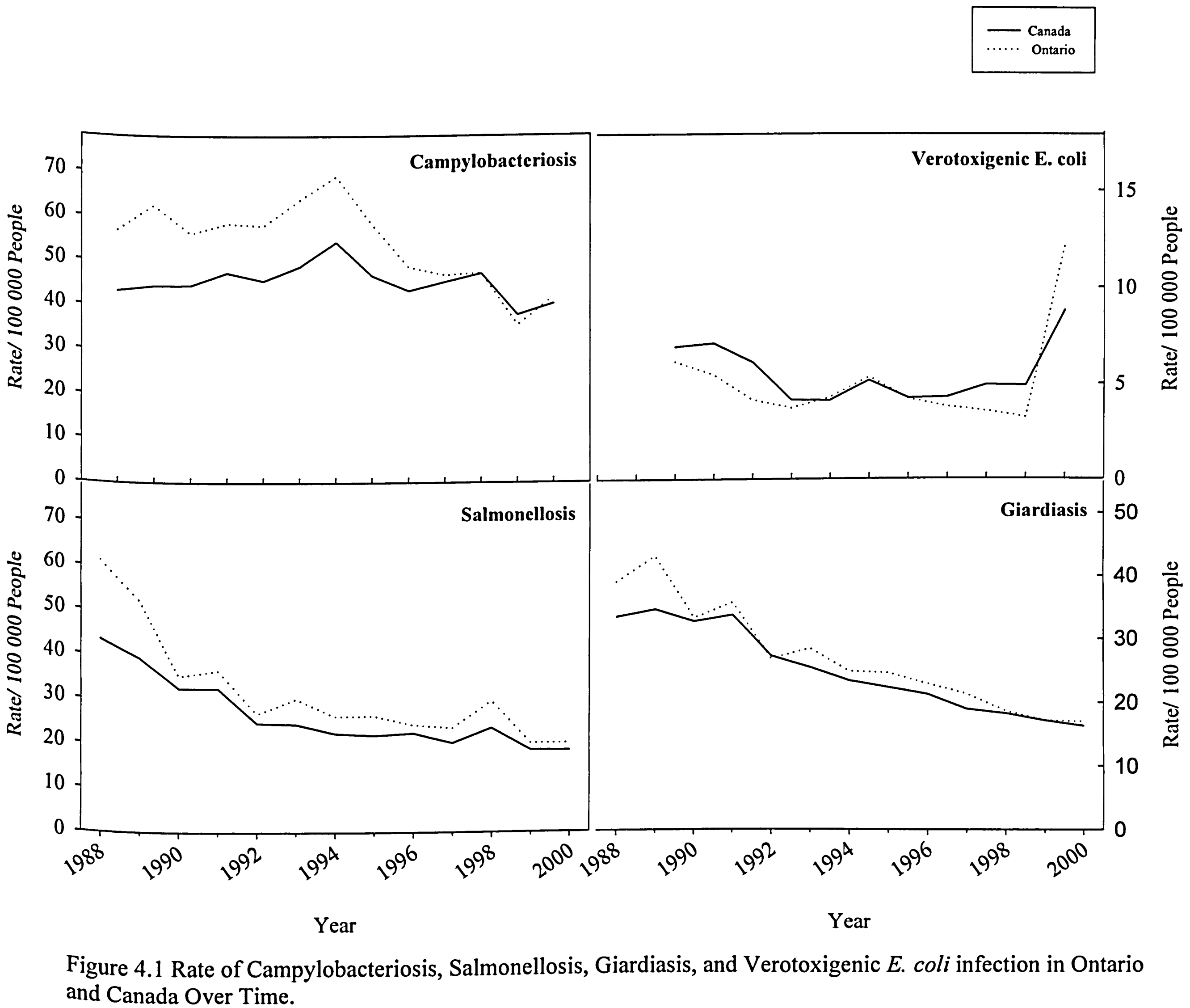

Figure 4.1 Rate of Campylobacteriosis, Salmonellosis, Giardiasis, and Verotoxigenic *E. coli* infection in Ontario and Canada Over Time.
Generated from: The Public Health Agency of Canada. (2005). *Notifiable Disease Incidence by Year, 1988-2000.*

Cryptosporidium parvum and *Escherichia coli* O157:H7 are considered to be emerging waterborne pathogens. Nwachcuku and Gerba (2004) suggest that new pathogens continue to emerge due to: (a) increases in sensitive populations, (b) globalization of commerce and travel,

(c) development of molecular methods for detection, (d) changes in drinking water treatment technology, (e) changes in food supply production, and (f) evolution of organisms leading to genetic reassortment. The evolution of organisms has been speculated to be the result of bacterial resistance. Bacterial resistance is becoming increasingly common as anti-microbial agents such as disinfectants and human and animal antibiotics enter the environment through diffuse pathways (Rooklidge, 2004; Ewen, 1999; Aga *et al.*, 2005; Sobsey *et al.*, 2001) ultimately leading to the development of resistance against drug therapies. A review of disease incidence and manure-related human endemics suggest that *Salmonella enterica, Campylobacter jejuni, Escherichia coli* O157:H7, *Cryptosporidium parvum* and *Giardia lamblia* regularly threaten water quality in agricultural areas given extended survival times and transport characteristics that favour the movement of these pathogens over long distances. Sources, survival characteristics, and infective doses for these pathogens are summarized in Appendix 4.3. For an in depth review of survival and transport characteristics of these pathogens the reader is referred to Kelly, 2005 and Stiefelmeyer, 2003.

4.3 Bacterial Diseases

4.3.1 Salmonellosis

Salmonellosis is characterized by nausea, vomiting, and diarrhea (World Health Organization [WHO], 2004) and is caused by the enteric pathogen *Salmonella enterica*. In children, the elderly, and immunocompromised individuals, infection may spread to the bloodstream and result in death if not properly treated with antibiotics (PHAC, 2003c). *Salmonella* species can sustain extended periods of time in soil and water and can survive in temperatures between 8 and 45°C (Bicudo and Goyal, 2003; p. 118).

4.3.2 Verotoxigenic *E. coli*

Verotoxigenic *E. coli* is characterized by mild to severe diarrhea which can be effectively treated by antibiotics within five to ten days of exposures (PHAC, 2003d). The disease can, however, be potentially fatal in children. Children under five years of age are at risk of developing haemolytic uraemic syndrome (HUS) leading to acute renal failure and haemolytic anaemia (WHO, 2004). There are a number of enteropathogenic strains of *E. coli* and are categorized based on virulence. Enterohaemorrhagic *E. coli* (EHEC), such as O157:H7 has been determined to be the leading cause of recent manure-related human epidemics (Smith and Perdek, 2004). The World Health Organization (2004; p. 230) reports that infection from the ingestion of drinking water requires as little as 100 EHEC organisms, although earlier studies by Griffin and Tauxe (1991) suggest the minimum infective dose is less than 10 viable cells. *E. coli* is capable of growth when exposed to low temperatures (Bicudo and Goyal, 2003) and are acid resistant (Hancock *et al.*, 2001). Estrada *et al.* (2004; p. 194) found that *E. coli* populations were undetectable in soil/sludge mixtures after a period of 80 days. Pathogen survival can also be significantly affected by soil type which varies considerably over small geographic scales.

4.3.3 Campylobacteriosis

Campylobacteriosis is a self-limiting condition characterized by abdominal pain, fever, nausea, vomiting, and diarrhea (PHAC, 2003). The most frequently isolated species in human infection is *C. jejuni*. Complications of the disease include arthritis, meningitis, and Guillaume-Barre syndrome (PHAC, 2003e).[48] *Campylobacter* species are generally sensitive to environmental stresses and are unable to survive under limited moisture conditions (Bicudo and Goyal, 2003). Compared to other bacterial pathogens, the infective dose is considered to be high. The World Health Organization (2004; p. 228) reports that for infection to be established from the ingestion of drinking water, 1, 000 organisms would be required. Other estimates for the consumption of milk suggest that the ingestion of 500 (Robinson, 1981) and 800 (Black *et al.*, 1988) organisms would cause illness (both cited in Rosenquist *et al.*, 2003; p. 91).

4.4 Protozoan Diseases

4.4.1 Cryptosporidiosis

Cryptosporidiosis in humans is characterized by diarrhea, malabsoprtion, and wasting (Tzipori and Ward, 2002) and is caused by the protozoan parasite *Cryptosporidium parvum*. In immunologically healthy individuals, the disease is self-limiting (Deng and Cliver, 1999) while in individuals with compromised immune systems (such as persons infected with HIV)

[48] Guillaume-Barre syndrome is an acute infection of the peripheral nerves. It causes progressive weakness and paralysis and may lead to death (PHAC, 2003e; World Health Organization [WHO], 2004).

Cryptosporidiosis may be life-threatening due to a lack of effective treatments (Fayer, 2004; WHO, 2004; Rochelle *et al.*, 2005). Like many waterborne parasites, *Cryptosporidium* forms a resistant oocyst that is capable of survival under environmentally-stressed conditions. Oocyst resistance is often observed in the presence of physical and chemical disinfection methods and can be attributed to the exogenous surface which is comprised of multiple polymeric layers (Gajadhar and Allen, 2004). Even in mild weather conditions (20°C), oocysts remain viable for over six months (Gajadhar and Allen, 2004; p. 7). The infective dose is estimated to be 30 oocysts (Finch and Belosevic, 2002; p. 19) although experiments conducted by Okhuysen *et al.* (1999) suggest that the infective dose varies among different isolates of *C. parvum*. The ID_{50} ranged from 9 to 1, 042 oocysts where a presumed infection was used as a variable (Okhuysen *et al.*, 1999; p. 1277).[49, 50]

4.4.2 Giardiasis

Giardiasis in humans is characterized by acute and chronic forms of diarrhea and associated weight loss (Heresi *et al.*, 2000) and is caused by the protozoan parasite *Giardia lamblia*. Left untreated, the disease may also result in complications such as arthritis and damage to cells which line the intestine (PHAC, 2003f). The transmission stages of *Giardia* are known as cysts. *Giardia* cysts are highly resistant (Bicudo and Goyal, 2003) compared to the trophozoite form which dies when excreted from the body (PHAC, 2003f). Experiments conducted by Olson *et al.* (1991; p. 1995) showed that after one week of storage at -4°C, the number of *Girardia* cysts contained in water, soil, and feces was dramatically or completely eliminated, while storage at 4°C indicated that the cysts could be detected for up to 9 weeks. The infective dose is estimated to be between 50 – 100 cysts (Finch and Belosevic, 2002; p. 18).

4.5 Ranking of Pathogens

Microorganisms are capable of survival within various environmental conditions and a number of variables exist that contribute to the efficacy of transmission to human hosts. These variables include minimum effective dose, frequency of pathogen occurrence, survival of

[49] ID_{50} refers to the number of pathogens required to cause infection in half of the exposed hosts.
[50] A presumed effect is defined by diarrheal illness or enteric symptoms. In contrast, a confirmed infection is defined by the presence of fecal oocysts (Okhuysen *et al.*, 1999).

microorganisms, possible removal by soil, and host susceptibility (Bicudo and Goyal, 2003; p. 116). To adequately address the research objectives identified in Chapter One, the selection and ranking of relevant pathogens will assist in determining which pathogens present the greatest risk to human health following the consumption of contaminated drinking water. The intended goal of this exercise is to determine operational conditions that warrant the implementation of a biosecurity program that includes measures to treat manure prior to land application and storage. Relevant pathogens were ranked according to prevalence and persistence. While the infective dose may be used to establish the extent of inactivation required during manure treatment, it was not considered as a criterion in determining where biosecurity programs should be established given that the infective doses are relatively low. Infective doses range considerably among the relevant pathogens.[51] For each criterion, the pathogens were ranked on a scale from 1 to 5, where 1 represented the highest persistence and the greatest prevalence. Where applicable, the comparison was conducted separately for cattle manure and swine slurry.

4.5.1 Prevalence

The prevalence of enteric pathogens in cattle manure and swine slurry was not reported as average values for the majority of pathogens reviewed. The range in values suggests that the prevalence of enteric pathogens in cattle manure and swine slurry is highly variable and not predictable. In order to compare and rank the values, the average value was calculated.[52] For instance, the prevalence of *Cryptosporidium* is reported to be 1 – 100% in cattle manure, and 0 – 10% in swine slurry (Table 4.3). Similar ranges in values were also reported for *Salmonella* and *Giardia*. Only *E. coli* O157:H7 and *Campylobacter jejuni* were reported as average values. The variability may be due to a number of different factors such as the diet, age, and condition of an animal, quality of water used for animal consumption, and climatic conditions (Miller *et al.*, 2003).

[51] The minimum infective dose for *Cryptosporidium* and *Giardia* is 30 oocysts and 50 cysts, respectively. Among the bacterial pathogens, *E. coli* 0157:H7 was found to have the lowest infective dose (Appendix 4.3 and 4.4).

[52] The average value from the range was calculated using the following formula: $x = a_1 + [(a_2 - a_1)/2]$ where x = average of distribution; a_1 = minimum value; and a_2 = maximum value.

Table 4.3: Prevalence of Enteric Pathogens in Various Livestock

	Livestock					
	Cattle			Pigs		
Pathogen	Range[1] (%)	Average (%)	Rank[2]	Range[1] (%)	Average (%)	Rank[2]
Salmonella spp.	0-13	6.5	4	0-38	19	1
E. coli O157:H7	16	16	3	0.4	0.4	5
Campylobacter jejuni	1	1	5	2	2	4
Giardia lamblia	10-100	55	1	1-20	10.5	2
Cryptosporidium spp.	1-100	50.5	2	0-10	5	3

1. Source: Olson, M.E. (2001, June). *Human and animal pathogens in manure.* Presented at Livestock Options for the Future, Winnipeg, Manitoba; p. 1.
2. 1 = Most prevalent; 5 = Least prevalent.

To accurately compare and rank the values, the average percent prevalence was taken. Prevalence of *E. coli* varied considerably between cattle and pigs. While the prevalence of *E. coli* O157:H7 in cattle manure was 16%, it was only in 0.4% of swine slurry samples examined. In contrast, the prevalence of *C. jejuni* was almost equivalent in cattle and swine samples. In cattle manure, *C. jejuni* was prevalent in 1% of the samples and in pig slurry, the pathogen was found in 2% of the samples.

4.5.2 Persistence

Survival characteristics were also reviewed to determine how long the pathogens were likely to persist in cattle manure and swine slurry.[53] Pathogen persistence varies according to ambient temperature differences brought on by seasonal changes. Pathogen persistence for cattle manure was reported for frozen, cold (5°C), and warm (30°C) weather conditions. Survival times for the pathogens under review are greatest during frozen and cold weather conditions (Appendix 4.3). Given that there is a potential for manure to run-off over frozen soils, the application of manure on farms that are provincially regulated under the *Nutrient Management Act* (2002) is prohibited on land that is subject to flooding or that drains into surface water during the winter

[53] Cow manure is typically collected and handled as a solid and consists of > 15 % dry matter. Slurry is typically collected in swine operations and consists of 5-10% dry matter. For more detailed information on the composition of animal manures, the reader is directed to Section 5.1.

and other times when soil is snow-covered or frozen.[54] As a result, persistence under frozen conditions was not included in this review. In order to compare and rank the values, average values were calculated according to the same formula used in Section 4.4.1.

Bacterial pathogens were found to be more persistent in cattle manure, while protozoan pathogens were more persistent in swine slurry. *E. coli* O157:H7 is capable of surviving for over 100 days and *Salmonella* is capable of surviving anywhere from 87 – 196 days in cattle manure. In contrast, these same pathogens have been reported to die off after 10 – 13 days when found in swine slurry (Table 4.4).

Table 4.4: Persistence of Enteric Pathogens in Cattle Manure and Swine Slurry

	Cattle Manure[1]			Swine Slurry		
Pathogen	Persistence[2] (days)	Average (days)	Rank[3]	Persistence[2] (days)	Average (days)	Rank[3]
E. coli O157:H7	> 100	> 100	2	10 – 100	55	4
Salmonella spp.	84 - 196	140	1	13 – 75	44	5
Campylobacter jejuni	7 - 21	14	4	> 112	> 112	3
Giardia lamblia	7	7	5	365	365	2
Cryptosporidium spp.	56	56	3	> 365	> 365	1

1. Values are based on average temperature conditions of 5°C.
2. Source: Olson, M.E. (2001, June). *Human and animal pathogens in manure.* Presented at Livestock Options for the Future, Winnipeg, Manitoba; p. 9.
3. 1 = Most persistent; 5 = Least persistent.

A similar pattern is observed among the protozoan pathogens. *Cryptosporidium* and *Giardia* are capable of surviving for 365 days in swine manure, but their persistence in cattle manure is noticeably lower. Survival rates of 7 and 56 days have been reported for *Giardia* and *Cryptosporidium*, respectively (Table 4.4). The range in values suggests that the persistence of enteric pathogens in cattle and swine is highly variable and not predictable.

4.5.3 Prioritizing Pathogen Inactivation

Of the waterborne pathogens that present the greatest risk to human health in Ontario, prevalence and persistence vary considerably among swine and cattle populations. In cattle populations, the protozoan parasites *Giardia* and *Cryptosporidium* are the most prevalent pathogens. In contrast, the bacterial pathogen *Salmonella* is the most prevalent in swine

[54] O. Reg. 267/03 also regulates the application of manure on all other lands [s. 48] during the winter and when the soil is snow-covered or frozen (Appendix 4.5).

populations, followed by protozoan parasite *Giardia*. The pathogens determined to be the most prevalent among both cattle and swine populations are not, however, the most persistent in the environment. In cattle populations, *Salmonella* and *E. coli* are the most persistent, while in swine populations, *Cryptosporidium* and *Giardia* are the most persistent.

Admittedly, manure-related human epidemics have been attributed to those pathogens that are capable of survival for prolonged periods of time rather than those that are the most prevalent. This association is the result of an increased potential for pathogens to remain viable after being transported to sources of drinking water. Due to the highly resistant nature of protozoan parasites, methods designed for pathogenic inactivation should not be based on *Escherichia coli* (WHO, 2004) even though it may be highly prevalent in animals. As such, prevalence alone should not be used to determine which operations would benefit the greatest from a biosecurity program. To establish a correlation between livestock and pathogen, persistence was plotted against prevalence for each pathogen using a scale from 1 to 5, where 1 represented the highest persistence and the greatest prevalence (Figure 4.2).

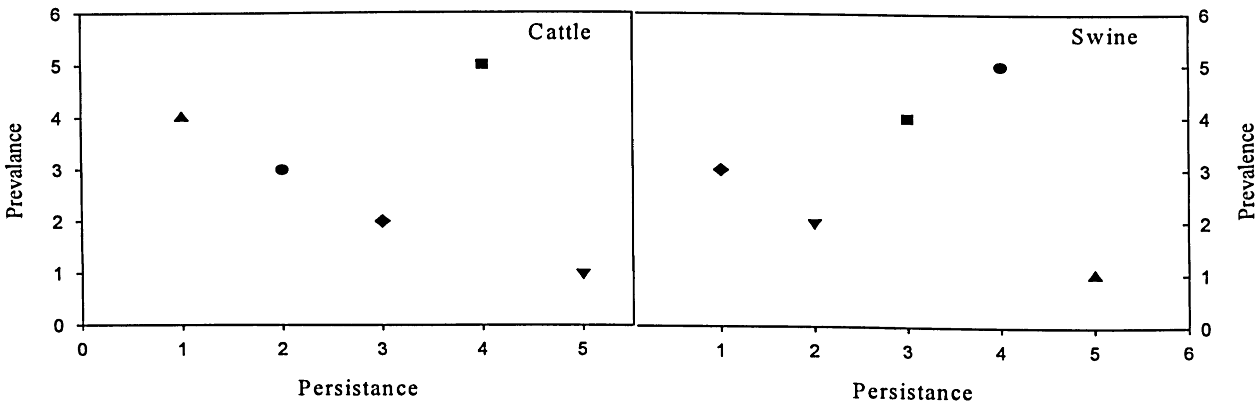

Figure 4.2: Prevalence vs. Persistence in Cattle and Swine Populations
▼ = *Giardia*; ▲ = *Salmonella*; ● = *E. coli*; ■ = *Campylobacter* and ♦ = *Cryptosporidium*

In both cattle and swine populations, the most prevalent pathogens were the least persistent. *Cryptosporidium* and *E. coli* demonstrated both persistence and prevalence in cattle populations. By comparison, *Giardia* and *Cryptosporidium* demonstrated both persistence and prevalence in swine populations.

4.6 Summary

Although most waterborne diseases have experienced a decline since 1990, there continue to be high rates of disease in Ontario and across Canada. Diseases currently under surveillance in Canada include Verotoxigenic *E. coli* infection, Campylobacteriosis, Giardiasis, Salmonellosis, and Cryptosporidiosis. Outbreaks of these diseases have been linked to the contamination of source water by agricultural operations. The selection and ranking of relevant pathogens determined which pathogens present the greatest risk to human health following the consumption of contaminated source water. Given that manure-related human epidemics have been attributed to those pathogens that are capable of survival for prolonged periods of time rather than those that are the most prevalent, persistence was also used to determine which operations would achieve the highest levels of pathogen reduction from a biosecurity program.

A review of the prevalence and persistence of notifiable pathogens in cattle and swine populations determined that the most prevalent pathogens were the least persistent. *Cryptosporidium* and *E. coli* demonstrated both persistence and prevalence in cattle populations. By comparison, *Giardia* and *Cryptosporidium* demonstrated both persistence and prevalence in swine populations. The association between pathogen and animal has determined which operational conditions warrant the implementation of a biosecurity program. However, the expected efficacy of a biosecurity program will be limited by the availability of controlled, replicated studies conducted at the commercial-scale.

CHAPTER FIVE: PATHOGEN INACTIVATION IN MANURE

5.1 Manure Management

Manure management is an essential component of animal production operations. Historically, manure management has focused on nutrient retention and waste disposal with emphasis placed on eliminating or reducing problems associated with odours and aesthetics. Recent trends in agriculture have shifted the focus on animal wastes. Given their potential to serve as a reservoir for a wide variety of contaminants, it is now recognized that manure requires treatment prior to disposal to protect against environmental and human health impacts. There is a growing body of scientific evidence to confirm the presence of contaminants in manure and their effects when released into the environment. These contaminants include: (a) organic matter, (b) urea, (c) ammonia, (d) nitrous oxide, (e) phosphorous, (f) methane, (g) carbon dioxide, (h) pathogens, (i) antibiotics, and (j) hormones (Aillery *et al.*, 2005). In livestock and poultry operations, these contaminants can be introduced into the environment via production houses, storage structures, and land where the manure is applied.

The composition of manure plays an important role in the development of a management regime. Depending on the percentage of total solids, manure can be characterized as a solid, semi-solid, or liquid (Table 5.1).

Table 5.1: Characteristics of Solid, Semi-Solid, and Liquid Manure

	Manure Characteristics		
	Solid	**Semi-solid**	**Liquid**
% Solids	> 20 %	10 – 20 %	< 8 – 10 %, but as low as 1 – 2 %
Description	• Combination of urine, bedding and feces • No water is added • Found in loafing barns, bedded pack, calving pen or open lot with good drainage	• Contains little bedding • No water is added	• Water is added to create a fluid mixture • Found in flushing and lagoon systems
Storage	• Open or covered stacking slab, with or without retaining walls	• Above-ground roofed storage • Outside structure that allows drainage	• Below-ground tanks (underneath or separate from the building • Earthen storage basins • Above-ground tanks
Application	Box or flail spreading equipment	Box or flail spreading equipment	Tank wagons or irrigation

Generated from: Veenhuizen, M.A., Eckert, D.J., Elder, K., Johnson, J., Lyon, W.F., Mancl, K.M., and Schnitkey, G. (Eds.). (1992). *Ohio Livestock Manure and Wastewater Management Guide: Bulletin 604*. Columbus, OH: Ohio State University College of Food, Agricultural, and Environmental Sciences.

5.2 Collection, Storage and Application of Manure

The collection of manure is highly dependent on the type of facility used to house animals. In operations where animals are confined, there are two main types of facilities; open-lot and sheltered (Figure 5.1). Open-lot facilities are unroofed areas where animals are confined by fences and are fed and watered at that location. Manure is mechanically scraped and collected from the lot and transferred to a storage area. Given that open-lot facilities are subject to run-off, they require additional design considerations to control the movement of soil, chemicals, and debris (Veenhuizen *et al.*, 1992). In comparison, sheltered facilities are roofed areas where animals are confined by walls and are commonly employed in large-scale livestock operations. As in the open-lot facility, manure can be mechanically scraped and collected from the lot and transferred to a storage area. Flushing systems are also commonly employed in sheltered facilities to allow for the removal of manure in areas of the building that are not accessible by machinery. In a flush system, large volumes of water flow through the building through sloped gutters where manure collects and is transferred to storage areas through gravitational flow or through pumping (Veenhuizen *et al.*, 1992). Alternatively, manure can be directly transferred from the animals to storage areas located below the building using slotted or woven-wire floors (Veenhuizen *et al.*, 1992).

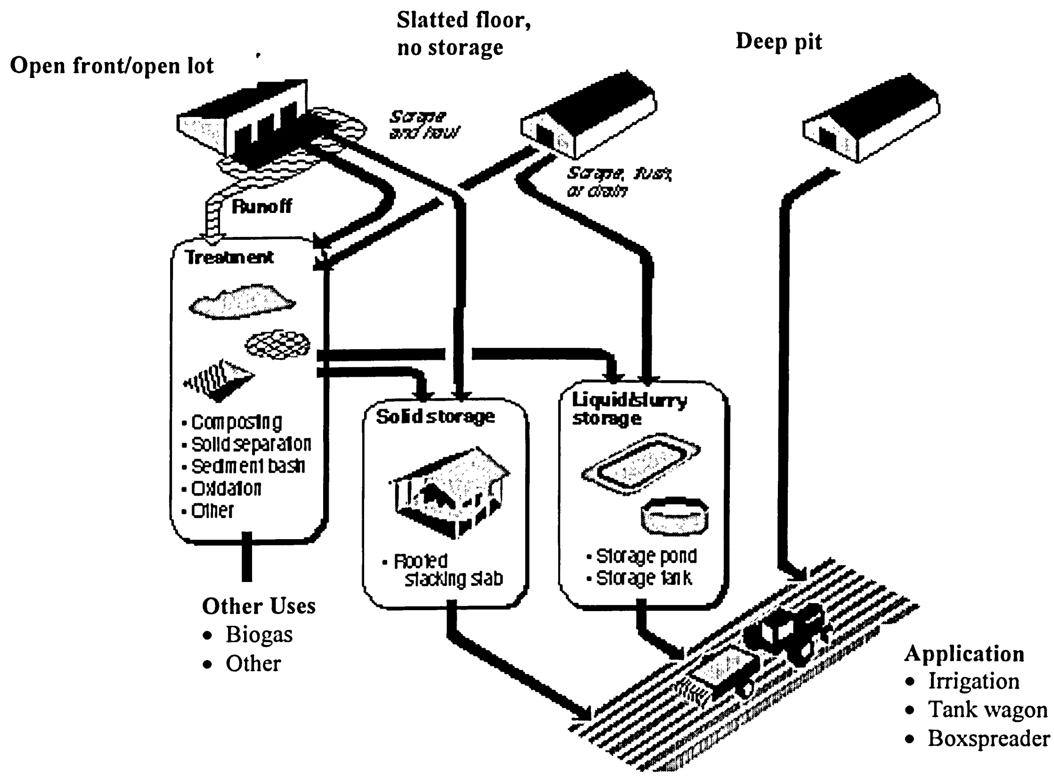

Figure 5.1: Manure Handling and Storage
Source: Jacobson, L.D., and Schmidt, D.R. (1994). *Manure Management Practices for the Minnesota Pork Industry* (FO-06456). University of Minnesota, MN: University of Minnesota Extension Service. Communication and Educational Technology Services.

Manure characteristics also influence how storage issues will be addressed. As the solid content decreases, manure becomes increasingly difficult to adequately contain. As such, the design and construction specifications for liquid manure storage facilities must include features to prevent accidental releases. In Ontario, Regulation 267/03 (General) currently addresses storage facility construction. On farms that are provincially regulated through the *Nutrient Management Act* (2002), both solid and liquid manure storage facilities are required to meet design and construction conditions. Earthen storage basins are commonly used to hold liquid manure and open-lot run-off. These basins are often referred to as lagoons. Earthen basin construction depends on a number of environmental conditions such bedrock, water table levels, and the hydraulic conductivity of the soil (Veenhuizen *et al.*, 1992). The hydraulic conductivity of the soil will determine whether the earthen storage basin requires the use of synthetic liners to minimize soil and water contamination.[55] Below-ground storage tanks are also used to hold liquid manure, but must be designed to withstand earth, hydrostatic, and storage loads (Veenhuizen *et al.*, 1992) in order to minimize leaks and subsequent soil, surface, and groundwater contamination.[56] In areas where below-ground, or earth basin construction is restricted, above-ground units are commonly installed (Figure 5.1).

Both solid and semi-solid manure requires storage facilities that allow for adequate drainage to retain the original solid or liquid characteristics of the manure. Manures that contain solids are often stored on concrete slabs, or piled directly on earthen floors rather than placed in tanks.[57] Semi-solid manures may require specially designed fences that retain solids and allow liquid to drain through (Veenhuizen *et al.*, 1992). In addition, semi-solid manure may benefit from a roofed structure to divert rainfall from coming in contact with the waste. Manure containing enough solids can be stacked in an open area, but if the storage area is exposed to rainfall, drainage systems may be required to maintain the original proportion of solids in the manure and to prevent run-off. Ontario Regulation O. 267/03 also specifies setback distances from surface water, wells, floodplains, and drainage systems for permanent storage facilities.

Regardless of the type of facility used, adequate storage affords operators flexibility in field application to avoid soil and weather conditions that may harm plant and environmental health (Veenhuizen *et al.*, 1992). In addition, storage facilities offset the limitations of available land area for application. Like collection systems and storage facilities, the application of manure primarily depends on the proportion of solids (Table 5.1). Manures can be applied either by surface spreading or subsurface injection. Both solid and liquid manures can be spread on the surface of land, but liquid manure can also be injected directly into the soil. Injection systems direct the manure towards the root zone of the plant which optimizes nutrient needs and minimizes the risk of run-off (Ontario Ministry of Agriculture, Food, and Rural Affairs [OMAFRA], 2004). Although the direct application of animal manure to land has long been

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[55] On farms that are provincially regulated under the *Nutrient Management Act* (2002), O. Reg. 267/03 specifies that compacted soil liners must be tested for hydraulic conductivity by a professional engineer prior to use [s. 75 (1)] and must meet minimum requirements for thickness [s. 75 (2)].

[56] On farms that are provincially regulated under the *Nutrient Management Act* (2002), O. Reg. 267/03 specifies that concrete storage facilities be designed and inspected by a professional engineer [s. 71], operators ensure durability and corrosion resistance is maintained [s. 72 (1)], and meet a minimum thickness of 125 mm [s. 72 (2)].

[57] On farms that are provincially regulated under the *Nutrient Management Act* (2002), O. Reg. 267/03 specifies that the suitability of concrete floors for manure storage be determined by a professional engineer [s. 80 (a)] and that earthen floors consist of at least 0.5 m of hydraulically secure soil [s. 80 (b)].

regarded as an effective means of waste disposal, there are increasing environmental concerns about this waste management approach. In areas where manure is applied, there is a risk of field run-off and seepage following periods of rainfall or irrigation. This type of movement allows manure to reach bodies of water that may be used as sources for drinking water, including both surface and groundwater supplies (Bicudo and Goyal, 2003)

5.3 Manure Treatment

While manure treatment has traditionally been considered an optional step in management regimes, it is becoming increasingly accepted and used. Manure treatment processes can be physical, chemical or biological in nature and may be used alone, or in combination to meet a variety of management goals. For instance, the Government of Prince Edward Island (1999) identifies the following goals for manure treatment: (a) odour reduction, (b) nutrient or energy recovery, (c) pathogen or seed inactivation, (d) improved value as a fertilizer, (e) volume reduction, and (f) export. Most manure treatment processes are designed to convert manure into a more stable form (United States Environmental Protection Agency [US EPA], 2002a), although the intended uses for the manure determine the nature and extent of the treatment process. The first step in most treatment methods is the removal of solids. Solid-liquid separation helps to remove organic materials in the manure. Particle size in the influent, treatment technology characteristics, and the treatment time affect the separation efficiency (San Joaquin Valley Assessment Panel, 2005). The separated solids can be used as fertilizer, while the remaining liquid can be used for irrigation purposes or to flush manure from animal houses to storage areas (Veenhuizen *et al.*, 1992). Solid/liquid separation is normally achieved through the use of physical processes such as settling, centrifuges, filtering, drying, freezing, and incineration (Table 5.2).

Table 5.2: Physical Separation Processes commonly used to Treat Animal Manure

Process	Description
Settling	Gravity driven Manure is held in concrete or earthen basins to reduce velocity and allows solids to settle out
Centrifuges	Manure is spun in rotating drums at high speeds to produce a cake with 15-40% solids
Filtering and screening	Animal waste is held in a medium and forced through a filter by gravity, vacuum or pressure
Drying	Encouragement of water evaporation
Freezing	Dewatering to improve settling and filtering
Incineration	Manure is converted to an ash

Generated from: Veenhuizen, M.A., Eckert, D.J., Elder, K., Johnson, J., Lyon, W.F., Mancl, K.M., and Schnitkey, G. (Eds.). (1992). *Ohio Livestock Manure and Wastewater Management Guide: Bulletin 604.* Columbus, OH: Ohio State University College of Food, Agricultural, and Environmental Sciences.

As livestock operations continue to intensify, manure treatment has become increasingly important due the generation of large quantities of waste. The per capita fecal production of animals such as cattle and swine exceeds the amount of waste created by humans (Sobsey *et al.*, 2001; p. 54). An estimated 361 million kilograms of manure was produced daily by Canadian livestock in 1996, which translates into 132 billion kilograms of manure produced over the course of that year (Hofmann and Kemp, 2001; p. 3).[58] According to Hofmann and Kemp (2001; p. 3) the average production of manure in Canada was 755 kilograms per hectare, although a number of sub-sub-basins reached production values of over 5 000 kilograms per hectare (Appendix 5.1).[59] In fact, of the four sub-sub-basins identified that produced over 5 000 kilograms of manure per hectare, three were in Ontario. The Maitland, Upper Thames, and Grand watersheds are all located in south western Ontario (Appendix 5.2). Within high-density areas, poultry and dairy cattle make up the largest proportion of livestock in Ontario (Beaulieu *et al.*, 2001; pg. 15). However, the amount of manure produced is proportional to the number of animal units. As such, cattle and hogs are the greatest contributors to manure (Appendix 5.3).

Given that animal wastes often contain pathogenic microorganisms such as bacteria, protozoa and viruses, care must be taken to reduce the possibility of contamination of source

[58] Beef cattle, dairy cows, hogs, calves, poultry, horses and sheep were estimated to produce 52, 19, 16, 7, 3, 3, and $\leq$ 1% of the total amount of manure in Canada, respectively (Hoffman and Kemp, 2001; p. 3).

[59] There are five major basins in Canada that are divided into 218 sub-basins. Sub-basins can be further divided into 959 sub-sub-basins (Statistics Canada, 2001; p. 2).

water which can lead to subsequent human illness. Although the conventional definition of manure identifies the presence of feces, urine, and bedding materials, other sources of pathogens may be present. Pell (1997; p. 2673) cautions that secretions from the nose, throat, vagina, mammary gland, skin, and placenta can be found in manure.[60] As such, wastes need to be adequately treated in order to prevent the risks associated with human and environmental contact, especially where a large number of animals is confined in a relatively small space. Until recently, there had not been any human health incidents that would have warranted making pathogen reduction, as part of source water protection, a priority. As a result, pathogen reduction in animal manure has been a secondary consideration to nutrient stabilization (Zilberman *et al.*, 2005; p. 51), volume reduction, and temporary storage benefits (Vanotti *et al.*, 2005a, p. 1).

Pathogen inactivation has been identified as a research priority by the Agricultural Research Service in the United States.[61] A number of states have begun concentrating on pathogen inactivation through industry-supported research projects. For instance, in North Carolina, an agreement between Smithfield Foods/ Premium Standard Foods and the North Carolina Attorney General was made to support the development of technologies that were superior to conventional manure treatment practices (Vanotti *et al.*, 2005a and 2005b). In Canada, Agriculture and Agri Food Canada has a national research program in Soil, Water, and Air Quality. Pathogens are a priority in this program; however, microbial source tracking and incidence of pathogens in animal storage facilities were the only areas of current focus (Butts, R. personal communication; 6 March 2006). Furthermore, while the Provincial Government is planning to take steps to identify operations that will pose a significant threat to surface and ground water supplies, pathogen inactivation in animal wastes has not been recognized as a means of protecting Ontario's water quality.

Given that the risks presented by pathogens in manure have only recently received attention, a limited amount of research has been conducted on treatment processes. In addition, the majority of treatment technologies have not been investigated using field-scale trials which is an important consideration in evaluating the efficacy of available treatments. For instance, the

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[60] Bedding absorbs urine and fecal matter. Common bedding materials include loose sand, hay, sawdust, wood chips, cottin gin waste, and shredded newspaper (Robbins, 2005).
[61] The Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA) initiated the ARS Manure and Byproduct Utilization National Program. In 2004, areas identified for research priority included: (a) nutrient composition, (b) emissions, (c) pathogens, and (d) by-products (Hegg, 2005; p. 2).

San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel (2005) was established to evaluate the environmental and economic performance of manure treatment technologies. Their review was inconclusive given the lack of controlled, replicated studies conducted at the commercial-scale. It should also be noted that the extent to which pathogens are removed from animal waste can be uncertain due to limitations of recovery and detection methods (Sobsey *et al.*, 2001).

Admittedly, it is not practical, nor is it advantageous for manure treatment technologies to concentrate on a single contaminant. Due to the increasing number of regulations imposed on farm operators, treatment technologies continue to emerge that simultaneously address many of the concerns associated with the handling, storage, and land application of manure. To adequately address the research objectives identified in Chapter One, a review of currently available manure treatment technologies will assist in determining which technologies have demonstrated pathogen inactivation capabilities.[62] The intended goal of this exercise is to determine the estimated level of pathogenic reduction that can be achieved in manure. The scope of this study is limited to treatment technologies used for the inactivation of notifiable waterborne pathogens (or corresponding indicator species) in manure.[63] The review will also focus on technologies available for hog and cattle operations due to increasing commercialization of these industries in Ontario. Given the limited amount of research at the commercial-scale, laboratory-scale studies have been reviewed in this investigation. Experimental data for pathogen-bearing wastes other than manure have also been included to provide further clarity on treatment processes, or to demonstrate pathogen persistence where deemed appropriate.

5.4 Physical Methods of Pathogen Inactivation

5.4.1 Ultraviolet Irradiation (UV)

Due to increasing concerns about the use of chemicals for pathogen inactivation, alternative disinfection methods have been developed for a variety of commercial applications.

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[62] The review of available treatment technologies was completed in January, 2006.

[63] Pathogen load reductions are reported in log_{10}. A two, three, and four log_{10} reduction corresponds to 99, 99.9, and 99.99% removal efficiency, respectively.

Improvements in technology and cost-effectiveness (Hill *et al.*, 2002) have lead to the widespread use of Ultraviolet Irradiation (UV) as a method of disinfection. During UV disinfection, high-energy photons create pyrimidine dimers that are capable of denaturing deoxyribonucleic acid (DNA) (Shechmeister, 1985; as cited in Wong *et al.*, 1998; p. 416). The destruction of DNA prevents pathogens from reproducing and establishing infection in hosts (Rose *et al.*, 2002; p. 120).[64] As such, this type of disinfection is effective against bacteria, viruses, and parasites. The extent of disinfection is, however, influenced by a number of factors including the presence of suspended solids and humic acids.

The composition of liquid manure makes it an unfavourable candidate for UV disinfection due to the presence of suspended solids and dissolved organic compounds (Hill *et al.*, 2002; p. 92). To circumvent this limitation, Hill *et al.* (2002) proposed the use of UV on swine wastes following pre-treatment with an aerobic biofilter. In field-scale experiments, swine waste was flushed into a concrete settling basin and a rotary screen to separate the solids.[65] Following solids separation, wastewater was pumped into an aerobic biofilter system comprised of two consecutive biofilters at a rate of 5 450 L/d (Hill *et al.*, 2002; p. 92). Biofilter influent and effluent samples were collected and later subjected to a laboratory-scale, low-pressure UV collimated beam disinfection. The mean influent concentration for *Escherichia coli* and *Clostridium perfringens* was 6.6 and 3.2 $\log_{10}$ CFU/100 mL, respectively (Hill *et al.*, 2002; p. 93). Results showed that absorbed UV doses were lower in the biofilter system influent than in the effluent, suggesting that in the system influent, enteric microbes were more susceptible to UV irradiation than in wastewaters that have already undergone some type of treatment. At a UV dose of 6 mJ/cm^2, *Escherichia coli* were reduced by 2.1 $\log_{10}$ in the system influent and by 1.9 $\log_{10}$ in the first biofilter effluent (Hill *et al.*, 2002; p. 95). To achieve the same reduction in the second biofilter effluent, a higher UV dose of 13 mJ/cm^2 was required (Hill *et al.*, 2002; p. 95). In the same series of experiments, *C. perfringens* spores were the least susceptible to disinfection, average reductions of just 0.2 to 0.4 $\log_{10}$ (Hill *et al.*, 2002; p. 9). Although *C. perfringens* is not considered to be a concern in drinking water, its spores are removed from wastewater by the same physical separation processes that remove helminth ova and protozoan

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[64] DNA is the carrier of genetic information. It is comprised of the bases adenine, guanine, cytosine, and thymine which are linked by phosphodiester bonds (Atlas, 1997).

[65] Swine waste was flushed every three hours from a 500 head finishing facility (Hill *et al.*, 2002; p. 92).

cysts and oocysts. As a result, Hill *et al.* (2002; p. 97) consider *C. perfringens* to be a potentially useful indicator for the removal of more environmentally stable organisms such as *Giardia* or *Cryptosporidium* species.

5.4.2 Thermal Treatment

A host of experiments have been conducted to determine the temperature thresholds responsible for pathogen inactivation in manure. Thermal treatments employ the direct application of extreme hot or cold temperatures to induce pathogen inactivation. Composting, a process that relies on microbial activity to produce elevated temperatures that result in pathogen inactivation, is discussed in Section 5.6.1. Fayer and Nerad (1996) isolated *Cryptosporidium parvum* oocysts from experimentally inoculated calf manure. Neonatal mice were used to detect oocyst survival following exposure to temperatures below 0°C. Each mouse received a suspension of 10^6 oocysts through gastric intubation and after 72 to 96 hours, histological sections of mice were examined for parasites (Fayer and Nerad, 1996; pg. 1431).[66] Parasites could not be detected in mice exposed to *C. parvum* oocysts treated at -15°C for 168 hours, at -20°C for 24, and 168 hours and at -70°C for 1, 8, and 24 hours (Fayer and Nerad, 1996; p. 1432). Developmental-stage cryptosporidia were, however, detected in mice exposed to *C. parvum* oocysts treated at -10°C for 8, 24, and 168 hours, at -15°C for 8 and 24 hours, and at -20°C for 1, 3, and 5 hours (Fayer and Nerad, 1996; p. 1432). The authors suggest that in environments where a layer of snow covers materials containing oocysts, there is an insulating effect that prevents exposure to colder air temperatures (Fayer and Nerad, 1996) subsequently preventing oocyst inactivation. Similar experiments conducted by Sherwood *et al.* (1982; p. 473) found that *Cryptosporidium* species oocysts isolated from calf manure were inactivated within two weeks when stored at 15 to 20°C and inactivated within five days stored at 37°C. Isolates stored at 4°C, however, remained viable for up to four months (Sherwood *et al.*, 1982; p. 474). Initial oocyst concentrations were not reported. The rate of degradation of *Giardia* cysts and *Cryptosporidium* oocysts was also observed by Olson *et al.* (1991) in experimentally inoculated cattle feces.[67] The calf feces samples had initial concentrations of 10^5 *Giardia* cysts/gram or 10^7 *Cryptosporidium* oocysts/gram (Olson et al., 1991; p. 1993). *Giardia* cysts survived less than 1 week when stored

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[66] Microscopic sections of tissues.
[67] Fecal samples were collected directly from the animal and did not contain bedding or urine.

at -4°C, while exposure to a temperature of 4°C allowed the cysts to remain infective for 1 week (Olson *et al.*, 1991; p. 1993). *Cryptosporidium* oocysts were found to be significantly more resistant. Under similar storage conditions, the oocysts survived for 8 to 12 weeks. By increasingly the temperature to 25°C, oocysts were only able to survive for 4 weeks (Olson *et al.*, 1991; p. 1993).

Turner (2002) investigated the thermal destruction of *Escherichia coli* in experimentally inoculated pig feces (obtained directly from animals), wheat straw and farmyard manure (composed of straw, pig feces, and urine). In controlled laboratory experiments, 10 mL *E. coli* cultures were added to samples of pig feces, wheat straw, and farmyard manure. The initial concentration of *E. coli* 11943 ranged from 8.9 to 9.4 $\log_{10}$ CFU/mL in the pig feces, 9.3 to 10 $\log_{10}$ CFU/mL in the wheat straw, and 8.3 to 9.6 $\log_{10}$ CFU/mL in the farmyard manure (Turner, 2002; pg. 59-60). *Escherichia coli* were inactivated within one hour in pig feces under temperature conditions of 55°C, while exposure to 50°C for the same period of time failed to destroy the pathogen (Turner, 2002; p. 60).[68] By comparison, straw required a longer period of time before inactivation occurred. The inactivation of *E. coli* 11943 in straw was obtained within 2 hours at 55°C, while exposure to 50°C resulted in cell viability even after 72 hours (Turner, 2002; p. 59). *Escherichia coli* 11943 was also inactivated within 2 hours at 55°C in farmyard manure (Turner, 2002; p. 60). At 50°C, farmyard manure did require a longer exposure period, but complete inactivation of the marker strain was observed after 24 hours (Turner, 2002; p. 60). Moisture content was also monitored during this series of experiments. In pig feces and farmyard manure, survival rates of *E. coli* 11943 were not affected by moisture content. The authors did, however, observe that the inactivation of *E. coli* 11943 in straw using a 10 mL culture broth occurred more slowly than when 1 mL of broth was used at both temperatures tested, suggesting that moisture content may be an important factor in pathogen inactivation (Turner, 2002; p. 59). At elevated temperatures, the manure dries out, leaving little moisture available for cellular growth. The conditions observed in the laboratory-scale experiments were applied to a field-scale trial using one tonne of the same farmyard manure. The results are discussed in Section 5.6.1.

[68] *E. coli* 11943 is a non-toxic marker strain. By determining the minimum requirements for the inactivation of the marker strain, the conditions likely to affect the inactivation of similar pathogens may be inferred (Turner, 2002; p. 58).

Wang *et al.* (1996) also evaluated moisture content in laboratory-scale thermal inactivation experiments. The moisture content decreased from 81.2% to 7% in experimentally inoculated cattle feces after 42 days at 37°C (Wang *et al.*, 1996; p. 2568).[69] To mimic epidemiologic data for *E. coli* populations found naturally in calf feces, two inoculation levels of 10^3 and 10^5 CFU/g were used (Wang *et al.*, 1996; p. 2568). While the population of *E. coli* O157:H7 increased by 2 $\log_{10}$ during the first two days when exposed to 37°C (Wang *et al.*, 1996; p. 2568), by Day 21 the populations decreased to levels that were only detectable using an enrichment culture (Wang *et al.*, 1996; p. 2568).[70] In similar experiments conducted by Himathongkham *et al.* (1999) cattle manure and cattle manure slurry were experimentally inoculated with *E. coli* O157:H7.[71] In laboratory-scale experiments, *E. coli* O157:H7 were undetectable in cattle manure slurry after being exposed to 37°C for 27 days (Himathongkham *et al.*, 1999; p. 255). At the same temperature, *Salmonella typhimurium* was undetectable after 19 days of exposure (Himathongkham *et al.*, 1999; p. 255). Although temperatures of 20 and 4°C were also able to reduce bacterial counts in the manure slurry, neither population was reduced to non-detectable levels. At 4°C, *E. coli* O157:H7 was reduced by 3 $\log_{10}$ and *S. typhimurium* was reduced by 1.5 $\log_{10}$ on day 60 (Himathongkham *et al.*, 1999; p. 255). In contrast, neither *E. coli* O157:H7, nor *S. typhimurium* could be reduced to non-detectable levels in the cattle manure. The population of both pathogens increased during the first three days when exposed to 37°C. Following increases in population, *E. coli* O157:H7 and *S. typhimurium* were reduced by 6 $\log_{10}$ after 38 and 48 days, respectively (Himathongkham *et al.*, 1999; p. 253). Initial pathogen concentrations were not provided by the authors.

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[69] The inoculum consisted of a five-strain mixture of nalidixic acid-resistant *E. coli* O157:H7. The five strains included 932 (human isolate), E0122 (calf fecal isolate), C7927 (human isolate), E09 (meat isolate), and E0018 (calf fecal isolate) (Wang *et al.*, 1996; p. 2567).

[70] An enrichment culture is a technique in which environmental (including nutritional) conditions are controlled to favour the development of a specific organism or group of organisms (AAFC, 2003).

[71] Cattle manure slurry was prepared by mixing manure with deionized water at a ratio of 1:2 which mimicked the composition that is used during field application (Himathongkham *et al.*, 1999; p. 252).

5.5 Chemical Methods of Pathogen Inactivation

5.5.1 Chlorine Disinfection

Chlorine is a commonly used chemical disinfectant. Chlorination has traditionally been the preferred method for killing enteropathogenic bacteria and viruses in municipal water supplies due to effective pathogen removal and affordability (Atlas, 1997).[72] Many protozoan microorganisms are, however, resistant to chlorine disinfection or require high concentrations for effective removal. For instance, *Cryptosporidium parvum* can not be destroyed by chlorination at levels that are considered to be safe for human consumption (O'Donoghue, 1995). Other concerns surrounding the use of chlorine include corrosiveness, irritation to skin and eyes (Amas and Clark, 1999) and the potential formation of hazardous by-products. When natural organic matter reacts with free chlorine, halogenated organic by-products such as trihalomethanes may form (Sorlini and Collivignarelli, 2005). Trihalomethanes have been identified as possible human carcinogens (Li *et al.*, 2003) and linked to still births (King *et al.*, 2000) further supporting the eradication of chlorine as a disinfectant. Furthermore, given the concentration of disinfectants needed to adequately treat the amount of waste produced in livestock operations, this treatment option would likely be financially inhibiting.

Other chemicals that fall under similar scrutiny, but have been proven to be effective in pathogen disinfections include formaldehyde, potassium permanganate, and sodium hydroxide (Bicudo and Goyal, 2003). Himathongkham and Riemann (1999) evaluated the efficacy of ammonium sulfate and potassium hydroxide in reducing *Escherichia coli*, *Salmonella typhimurium*, and *Listeria monocytogenes* in experimentally inoculated chicken manure. Initial concentrations of 6.4, 4.7 and 5.7 $\log_{10}$ CFU/ g were reported for *E. coli*, *S. typhimurium* and *L. monocytogenes*, respectively (Himathongkham and Riemann, 1999; p. 181).[73] After 24 hours at 20°C, 4, 3, and 2.5 $\log_{10}$ reductions for *E. coli*, *S. typhimurium*, and *L. monocytogenes* were observed, respectively (Himathongkham and Riemann, 1999; p. 181). When exposure time at the same temperature was increased to 72 hours, *E. coli* and *S. typhimurium* were reduced by 8 $\log_{10}$ and *L. monocytogenes* was reduced by 4 $\log_{10}$ (Himathongkham and Riemann, 1999; p. 181).

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[72] Enteropathogenic bacteria are pathogenic bacteria that must adhere to mucous membranes in order for infection to be established (Atlas, 1997).

[73] Values are approximations extracted from a graph. The actual initial concentrations were not reported.

The amount of ammonia required to obtain similar results under field conditions would amount to 10 kg or 13 L liquid ammonia per ton manure (Himathongkham and Riemann, 1999; p. 182).

5.5.2 Liming

Many chemical treatments, with the exception of lime, are toxic and require elevated concentrations to inactivate persistent pathogens. Liming destroys pathogens through pH and temperature increases (Capizzi-Banas *et al.*, 2004) and can be used to combat acidic soil conditions (Turner and Burton, 1997). In field-scale experiments conducted by Capizzi-Banas *et al.* (2004; p. 3254), the viability of *Ascaris* eggs in naturally contaminated pig slaughterhouse sludge was determined. The initial concentration of *Ascaris* eggs was 924 eggs $^{+}/-$ 295 per 10 g solid (Capizzi-Banas *et al.*, 2004; p. 3253). Following the amendment of 22 to 26% CaO/Total Solids, a series of trials were conducted at 51, 55, and 58°C.[74] After 60 min, 40% inactivation was achieved following treatment at 51°C (Capizzi-Banas *et al.*, 2004; p. 3256). Increasing the temperature by 4 degrees killed all eggs after 75 minutes, while the time required for inactivation was dramatically decreased to five minutes with a further increase in temperature to 58°C (Capizzi-Banas *et al.*, 2004; p. 3256). To ensure successful inactivation, the authors recommend that sludges remain homogeneous mixtures with a pH of 12 or more. The successful application of liming to kill *Ascaris* eggs suggests that other highly resistant pathogens such as *Crypstosporidium* and *Giardia* could be inactivated under similar conditions (Capizzi-Banas *et al.*, 2004).

5.5.3 Plant-Derived Oils

A number of plant-derived oils have been investigated for their effectiveness as bactericidal agents in pure cultures. Varel and Miller (2001) investigated the use of carvacrol (5-isopropyl-2-methylphenol), thymol (5-methyl-2-isopropylphenol), and pinene to reduce odour and the presence of fecal coliforms in cattle manure slurry.[75, 76] A combination of carvacrol and

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[74] The swine sludge was treated with quick lime using a plough mixer. The lime dose was adjusted according to the dry matter of the sludge in order to reach a temperature range from 50° to 60°C. When the target temperature range was reached, silk bags containing 10^6 *Ascaris* eggs were inserted into the stockpiled sludge and removed based on inactivation kinetics reported for laboratory scale experiments (Capizzi-Banas *et al.*, 2004; p. 3254).

[75] Fecal coliforms were enumerated with *Escherichia coli* coliform count plates; however, the authors only reported the reduction of total anaerobic bacteria and fecal coliforms.

[76] Cattle manure slurry was produced by combining feces, urine, and distilled water in the ratio of 50:35:15 (Varel and Miller, 2000; p. 392).

thymol at 6.7 mM each and pinene at 3.8 mM resulted in a significant reduction in fecal coliforms after 4 days. At time 0, there were 46 x 10^5 cells of fecal coliforms/mL and after 4 days they were non-detectable (Varel and Miller, 2001; p. 1368). At these same concentrations, the pH remained at values between 6.5 and 7 which inhibited acid production or fermentation activity, further suggesting the potential for the reduction of odour emissions (Varel and Miller, 2001; p. 1368). Like liming, the use of plant-derived oils may also counteract soil acidification by maintaining neutral pH levels, generating favourable conditions for plant growth.

5.6 Biological Methods of Pathogen Inactivation

5.6.1 Composting

Organic material, such as animal waste, can be degraded by microorganisms through a process known as composting. When microorganisms digest organic matter, large amounts of heat are released. Carbon dioxide and water vapour are also released and over time, the volume and mass of the waste is reduced (San Joaquin Valley Assessment Panel, 2005; p. 24). Internal temperatures of un-stabilized compost reach the thermophilic range of 54 to 66°C when biological activity is at its greatest (Vanotti, 2005; p. 20). The process is both time and material dependent and as such yields highly variable results. Since oxygen is required for microbial activity during the composting process, the material must be frequently turned to reintroduce oxygen. In addition, the high moisture content of manure requires the use of bulking agents such as wood chips, corn stover, or leaves to further facilitate oxygen circulation (Veenhuizen *et al.*, 1992). Over time, and as food sources are depleted, microbiological activity decreases leading to lower temperatures in the compost (Vanotti, 2005) and results in a stabilized end-product. The finished product is rich in nutrients (Sidhu *et al.*, 2001) and can be used as a soil amendment or potting mixture.

A two-year compost study was conducted at the Agriculture and Agri-Food Canada Research Centre in Lethbridge, Alberta. Cattle manure was removed from feed-lot pens bedded with either straw or wood chips. Manure was placed in windrow piles on a concrete pad in a composting facility where it was exposed to ambient temperatures, but was protected from precipitation.[77] The compost was tested for the presence of both total coliforms and *E. coli* and windrow temperature was monitored. The average windrow temperatures were reported to be 33.5 to 41.5°C (Larney *et al.*, 2003; p. 1514). Since *E. coli* is a fecal coliform, its presence was used as a surrogate for specific pathogenic *E. coli* strains (Larney *et al.*, 2003) such as *E. coli* O157:H7. A 99.9% reduction in total coliforms and *Escherichia coli* was observed in cattle manure after composting for seven days (Larney *et al.*, 2003; p. 1514). On Day 0, the population of total coliforms averaged 7.86 $\log_{10}$ CFU/g soil and by Day 7, total coliforms had decreased to 1.69 $\log_{10}$ CFU/g soil in the first year of the study (Larney *et al.*, 2003; p. 1510-1511). Similar results were observed for *E. coli*. On Day 0, the value of *E. coli* averaged 7.57 $\log_{10}$ CFU/g soil and by Day 7, *E. coli* had decreased to 3.29 $\log_{10}$ CFU/g soil (Larney *et al.*, 2003; p. 1511). The population of total coliforms was however seven times higher on Day 94 than on Day 45 during the first year of the study, suggesting re-growth had occurred (Larney *et al.*, 2003; p. 1511). Regardless, the authors concluded that the thermal kill limit of 55°C suggested in composting guidelines is overly cautious given the rate and degree of pathogen inactivation observed using a mesophilic temperature range during their experiments.[78] In comparison, in aerated piles of experimentally inoculated sheep and cattle manure exposed to environmental conditions, the background concentrations of *E. coli* O157:H7 remained 10^5 to 10^6 CFU/g (Kudva *et al.* 1998; p. 3167).[79]

Maintaining elevated temperatures required for pathogen inactivation has been a common problem for many researchers investigating the merits of composting. Moisture content, substrate availability, C:N ratio, air supply rate, bulk density, porosity, wind speed, solar radiation,

[77] Windrow piles were 10.6 to 11.4 m long, 2.5 m wide and 2.0 m high. In the first year of the study, windrows were turned 16 times and in the second year of the study, windrows were turned 7 times (Larney *et al.*, 2003; p. 1509).
[78] The Canadian Council of Ministers of the Environment (2005; pp. 15-16) recommends that the following criteria be met for each of treatment options available when compost contains feedstock other than yardwaste: (a) the material should be maintained at an operating condition of 55°C or greater for three days using an *in-vessel* composting method, (b) the material should be maintained at an operating conditions of 55°C or greater for at least 15 days using the *windrow* composting method (turning the windrow at least 5 times), or (c) the material should be maintained at an operating condition of 55°C or greater for three days using the *aerated static pile* composting method (covering the windrows with an insulating material). The organism content of the final material must also meet one of the following criteria: (a) < 1 000 fecal coliform MPN/ g total solids calculated based on dry weight, or (b) no *Salmonella* species with a detection level < 3 MPN/4g total solids calculated based on dry weight.
[79] Sheep manure was collected daily for two months and divided into 27 piles. Each pile had a volume of approximately 50cm^3. Each pile was aerated by mixing prior to each sampling event. Cattle manure was collected daily for two months, aerated and divided into 10 piles. Each pile had a volume of approximately 100 cm^3 (Kudva *et al.*, 1998; p. 3167).

ambient temperature, and humidity can affect the temperature of compost (Turner *et al.*, 2005). When the outer most layer of a compost heap is exposed to ambient conditions, it often fails to reach the same temperature generated in the centre of the pile (Wu and Smith, 1999) limiting the inactivation of pathogens (Turner *et al.*, 2005). In preliminary thermal inactivation experiments conducted by Turner (2002; p. 61), *E. coli* 11943 were estimated to be inactivated in farm yard manure, straw, and pig feces when exposed to 55°C for more than 2 hours. Field trials using forcibly aerated compost windrows failed to reach temperatures higher than 35°C suggesting that composting may not an effective means of pathogen inactivation (Turner, 2002; p. 61). Inferring core temperatures is limited in its application due to various factors such as moisture, straw content, and air flow (Turner *et al.*, 2005). As such, the accurate detection of windrow temperatures may account for the variation among inactivation estimates in different experiments. Non-contact methods such as thermal imaging can provide a more accurate and timely estimate (Turner *et al.*, 2005) but may require a high level of expertise and would likely be cost prohibitive.

Several recommendations have been proposed to increase internal temperatures during composting. Wu and Smith (1999) suggest that the addition of an insulating layer, such as finished compost or wood chips, would eliminate exposure to ambient temperatures. The use of wood chips as an amendment to compost has also been linked to pathogen inactivation. Kudva *et al.* (1998) suggested that wood products such as woodchips, shavings and sawdust added to bedding material may contain anti-microbial compounds. By comparison, Larney *et al.* (2003; p. 1514) and Miller *et al.* (2003; p. 1891) reported that bedding type did not significantly affect total coliforms or *E. coli* in cattle manure. Sobsey *et al.* (2005) also noted that microbial concentrations in bulking agents can be comparable to untreated wastes and can result in an additional burden to treatment systems.

In addition to unpredictable temperatures, composting processes are susceptible to nuisances such as odours (Wu and Smith, 1999; Atlas, 1997), dust, and vectors (El-Ahraf *et al.*, 1984) which may lead to complaints or legal action taken by adjacent property owners against farm operators.[80] Composted materials are also prone to pathogen re-growth and subsequent

[80] Odours result from the incomplete degradation of carbohydrate, protein, and lipid components resulting in short-chain volatile fatty acids, aromatic chemicals, nitrogenous compounds, and sulfur-containing compounds (Varel and Miller, 2001).

public health risks. In experiments conducted by Larney *et al.* (2003; p. 1511) re-growth of total coliforms in cattle manure was observed between Day 45 and 94. Similar results were observed by Kudva *et al.* (1998). Non-aerated piles of sheep manure exposed to ambient conditions were cultured every 30 days to determine the presence of *E. coli*. The pathogen was consistently isolated from the manure for a period of one year. Cultures taken from the manure at month 13 and 14 tested negative for *E. coli*, while at month 21, the manure tested positive again (Kudva *et al.*1998; p. 3168). Re-growth is dependent on factors such as moisture content, bio-availability of nutrients, temperature and the presence of indigenous microorganisms (Sidhu *et al.*, 2001), but may also be attributed to contamination by machinery or the presence or vermin (Larney *et al.*, 2003).

The presence of indigenous microorganisms in composted materials has recently been linked to pathogen inactivation. There are a number of negative microbial interactions that may be responsible and include:

1. Competition – populations compete for the same resource.
2. Amensalism – production of an inhibitory substance.
3. Parasitism - one population is harmed by the other.
4. Predation – the consumption of one population by another (Atlas, 1997).

Sidhu *et al.* (2001) examined the survival of *Salmonella typhimurium* (9451) in sterilized and non-sterilized composted biosolids.[81] The authors demonstrated that the growth of artificially inoculated S. *typhimurium* was suppressed in non-sterilized samples of the biosolids that had been composted for two weeks. In sterilized biosolids, *S. typhimurium* reached a maximum population density of more than 10^8 CFU/g (Sidhu *et al.*, 2001; p. 916). By comparison, *S. typhimurium* was only able to reach a maximum population density of 10^3 CFU/g in non-sterilized samples (Sidhu *et al.*, 2001; p. 917). The effects of indigenous microorganisms were, however, less pronounced in composts stored for longer periods of time. In biosolids composted for two weeks, the inactivation rate of *S. typhimurium* was seven times higher than biosolids that had been composted for 117 weeks (Sidhu *et al.*, 2001; p. 917). Population densities of greater than 10^6 CFU/g were reached in all sterilized samples tested, suggesting that indigenous

[81] Composted biosolids were obtained from a commercial composting plant receiving anaerobically digested and dewatered biosolids from a wastewater treatment plant. The compost was artificially inoculated with rifampicin-resistant *S. typhimurium* (Sidhu *et al.*, 2001; p. 914).

microbial activity, rather than the availability of bio-nutrients was the growth limiting factor (Sidhu *et al.*, 2001; p. 916). Colonization and competition outcomes are, however, dependent on species characteristics. While the specific mechanisms of inactivation were not investigated, Sidhu *et al.* (2001; p. 918) suggests that growth inhibition may have been a function of inhibitory compounds, secondary metabolites, cell lysis due to the presence of phages, or the exhaustion of nutrients by highly active indigenous microorganisms. Despite this observation, there is little scientific evidence to support the potential use of indigenous organisms as a reliable method of inactivating pathogens in manure.

5.6.4 Constructed Wetlands

Constructed wetlands are designed to mimic the same processes that occur in natural wetlands. Physical, chemical, and biological processes work collectively to remove, immobilize or degrade a variety of contaminants (DeBusk and DeBusk, 2001) including pathogens. Pathogen removal in constructed wetlands is attributed to a combination of natural die-off, filtration, sedimentation, predation, UV degradation, and adsorption (Tousignant *et al.*, 1999). Due to the anoxic conditions that prevail in wetlands, Biological Oxygen Demand can not be effectively removed and as such, wetlands are more effective at removing contaminants from partially treated wastes. As a result, treatment wetlands are often one component of a larger system, and are preceded or followed by other treatment methods such as clarifyers, sedimentation ponds, or disinfecting units. In this respect, solid manure can not be treated using constructed wetland systems alone. Despite this limitation, constructed wetlands are able to process solids internally (DeBusk and DeBusk, 2001) and do not require sludge maintenance as compared to traditional treatment technologies.

Duggan *et al.* (2001; p. 170) studied the effectiveness of the common reed (*Phragmites australis*) for the removal of pathogens from chicken litter collected from a 30 000 head egg laying farm.[82] Two separate sub-surface flow reed beds were evaluated under sequential and continuous loading conditions. Under sequential loading conditions, the initial concentration of *E. coli* was 10^{11} CFU/100 mL and the initial concentration of *Campylobacter* was 100 CFU/ 100

[82] The litter was separated into 30 kg batches and mixed with 600 L of water to produce a slurry. Influent was added to the sequentially loaded reed bed for a period of 10 days, commencing in July and repeated in August. Influent was added to the continuously loaded reed bed for 19 days in August. Each bed measured 5.4 x 2.0 x 1.0 m with a 2% gradient (Duggan *et al.*, 2001; p. 170).

mL (Duggan *et al.*, 2001; p. 173-174).[83] Mean log reductions of 3.56 and 3.13 were obtained for *E. coli* and *Campylobacter* species, respectively using this loading practice (Duggan *et al.*, 2001; p. 171).[84] Under continuous loading conditions, the initial concentration of *E. coli* was 10^6 CFU/100 mL and the initial concentration of *Campylobacteur* was 6.0 x 10^4 CFU/100 mL (Duggan et al., 2001; p. 173-174). Mean log reductions of 4.25 and 2.96 were obtained for *E. coli* and *Campylobacter,* respectively (Duggan *et al.*, 2001; p. 171). In similar experiments, Hill and Sobsey (1998; p. 120) evaluated the use of constructed wetlands as a secondary treatment technique in reducing microbial concentrations in swine wastewater collected from a 2, 600 head nursery. The concentration of *Escherichia coli* in the anaerobic lagoon influent was 7.5 $\log_{10}$ CFU/100 mL, while the concentration in the constructed wetland influent was 5.2 $\log_{10}$ CFU/100 mL (Hill and Sobsey, 1998; p. 121). Primary treatment in an anaerobic lagoon resulted in a 2.1 $\log_{10}$ reduction of *E. coli*, while primary treatment in a constructed wetland achieved a 1.7 $\log_{10}$ reduction (Hill and Sobsey, 1998; p. 121).[85] The effect of combining these two treatments however, yielded significantly improved results. When primary treatment in the anaerobic lagoon was followed by secondary treatment in the constructed wetland, *E. coli* was reduced by an average of 3.8 $\log_{10}$ (Hill and Sobsey, 1998; p. 121). By comparison, primary treatment in an anaerobic lagoon resulted in a 0.2 $\log_{10}$ increase of total *C. perfringens* (spores + vegetative cells) from an initial concentration of 4.4 $\log_{10}$ CFU/100 mL (Hill and Sobsey, 1998; p. 121). Primary treatment in a constructed wetland resulted in a negligible reduction of 1.5 $\log_{10}$ (Hill and Sobsey, 1998; p. 121). The combination of these two treatments failed to decrease the concentration of *C. perfringens* any further. When primary treatment in the anaerobic lagoon was followed by secondary treatment in the constructed wetland, *C. perfringens* was only reduced by an average of 1.5 $\log_{10}$ (Hill and Sobsey, 1998; p. 121).

Rice *et al.*, (2005) also evaluated a constructed wetland system for swine wastewater, but incorporated a mechanical separator to remove solids prior to treatment in the wetland cells (Figure 5.2).

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[83] Values are approximations extracted from a graph. The actual initial concentrations were not reported.
[84] *E. coli* serotype not specified.
[85] Loading rate was estimated to be 1.5 x 10^4 L/d and Hydraulic Retention Time (HRT) was 270 days. The wetland was comprised of 2 cells each with dimensions of 3.6m x 36m and a slope of 0.1%. Loading rates were 4.5 and 2.5cm/d for cells 1 and 2, respectively (Hill and Sobsey, 1998; p. 120).

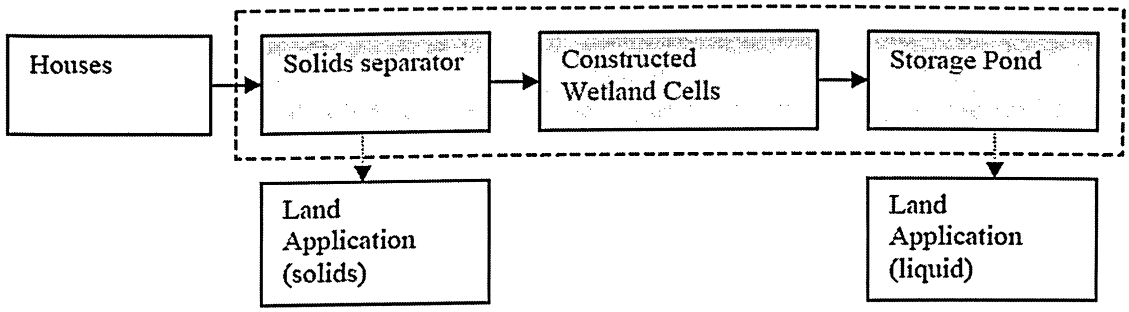

Figure 5.2: Process Flow Diagram of the Solid Separation/Constructed Wetlands Technology
Source: Williams, C. M. (2005). *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers.* Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 15.

Two wetland cells were planted with local rushes and cattails and received wastewater from a 3 520 head swine facility. [86] This system was successful in reducing microbial concentrations from the liquid waste stream. Compared to the barn flush, *E. coli*, *Salmonella* and *C. perfringens* were reduced in the treated effluent by an average of 4.63, 2.9, and 4.1 $\log_{10}$, respectively (Sobsey *et al.*, 2005; p. 6). Given that the system was only designed to treat the liquid waste stream, the microbial concentrations for the untreated solids remained relatively high. The average concentrations of *E. coli*, *Salmonella*, and *C. perfringens* in the untreated solids were 3.75×10^5 CFU/g, 17.3 CFU/g and 2.44×10^5 CFU/g, respectively (Sobsey *et al.*, 2005; p. 7).

5.6.5 Digestion

Animal wastes can be converted into fertilizer through the process of digestion. Digestion occurs naturally in earthen basins when the loading of organic material increases Biological Oxygen Demand (BOD) and leads to oxygen depletion (San Joaquin Valley Assessment Panel, 2005).[87] The resulting conditions support the growth of anaerobic bacteria that degrade the organic matter. The breakdown of organic matter produces a gas comprised of between 55 and 70% methane, with the remainder comprised of carbon dioxide, which can be used to produce

[86] The combined area of the wetland cells measures 8 acres. The loading rate was 25 kg/ha/day and the HRT was 12 days (Rice *et al.*, 2005; p. 2).
[87] Biological Oxygen Demand "is a measure of the amount of oxygen required by bacteria to degrade the dissolved and suspended organic matter in a volume of water" (Hemond and Fechner-Levy, 2000; p. 138).

heat and energy (US EPA, 2002a; p. 23). This gas is commonly referred to as biogas. While lagoons have been traditionally used to both treat and store animal wastes, digestion can be more fully controlled by using mechanical digesters. Mechanical digestion requires less treatment time and land area compared to lagoons. In addition, the biogas produced can be burned in order to heat the digester, although the amount of gas produced is highly dependent on the amount of manure being added to the system. For example, when 100 pounds of manure is added to a digester, only 4 pounds is converted to biogas (Veenhuizen *et al.*, 1992; "Treatment of Livestock Manure" Section).

The amount of heat required to facilitate digestion depends on the treatment goals of the digester. Psychrophilic, mesophilic, and thermophilic temperature ranges have all been successfully used in the digestion of animal wastes. [88] While most anaerobic digesters operate using mesophilic temperatures, thermophilic digestion has proven to be faster (San Joaquin Valley Assessment Panel, 2005; p. 28). Adequate mixing is also required to ensure bacteria remain in contact with the wastes to facilitate the breakdown of organic matter. Mixing can be achieved through the use of mechanical mixers, pumps, or bubbling with digester gas. Alternatively, plug-flow digesters can be used to maintain contact between bacteria and wastes by moving the wastes slowly through a tube-shaped vessel (Veenhuizen *et al.*, 1992).

Like collection, storage, and application processes, the type of digester used is highly dependent on the proportion of solids in the manure (Table 5.3). In fact, most conventional treatment technologies are only able to accommodate the digestion of wastes with < 5% solids (Zerring, 2005; p. 1). While plug-flow digesters are capable of processing semi-solid manure, lagoons should only be used to process liquid manure. Digesters are typically constructed below grade to allow for a gravity feed of the manure. This approach is also useful in cold weather climates to retain heat that may be lost from the system.

[88] Psychrophilic temperatures range from 15 to 20°C (Côté *et al.*, 2006; p. 687), mesophilic temperatures range from 20 to 40°C, and thermophilic temperatures range from 40 to 60°C (San Joaquin Valley Assessment Panel, 2005; p. 28).

Table 5.3: Types of Anaerobic Digesters

Type of Digester	Description	% Solids
Covered lagoon[1]	• Earthen storage facilities fitted with a floating cover to contain the biogas that is produced • Digestion depends on ambient temperature • Biogas production is variable	0.5 -3
Plug-flow digester[1]	• Consists of a long linear trough with an airtight cover that wastes slowly move through • Often constructed below grade • Mesophilic temperature range	11 – 13 %
Completely-stirred tank reactor (CSTR) [1]	• Large circular container • Mesophilic or thermophilic temperature range	3 – 10 %
Upflow anaerobic sludge blanket (UASB)[2]	• Bacteria conglomerate together and settle to the bottom of a tank • The settled material forms a sludge blanket	0 – 4 %
Anaerobic sequencing batch reactor (ASBR) [3]	• Activated sludge process based on 'fill and draw' • Sequence of partially filling the tank followed by aeration, settling, and decanting	N/A

1. Source: San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel (2005). *An Assessment of Technologies for Management and Treatment of Dairy Manure in California's San Joaquin Valley*. San Joaquin, California: Author; p. 29.
2. Source: Kalyuznyi, S., Sklyar, V., Fedorovich, V., Kpvaleve, A., Nozhevnikov, A., and Klapwijk, A. (1999). The development of biological methods for utilization and treatment of diluted manure streams. *Water Science and Technology,* 40 (1): 223-229. As cited in Ferreira *et al.*, 2003; p. 102.
3. Source: British Columbia Ministry of Agriculture, Food, and Fisheries. (1993). *Sequencing Batch Reactor Waste Treatment System*. Victoria, Canada: Author.

Anaerobic lagoons fail to reduce contaminant loads as effectively as mechanical digesters. Olsen (1988; p. 19) incorporated anaerobic filters into pilot-scale reactors run at 35°C.[89] Reactors were continuously fed to measure bacterial reductions in liquid swine manure inoculated with *Salmonella typhimurium* and tetracycline-resistant *Escherichia coli* O8. Both pathogens were artificially added to the slurry at concentrations of 5×10^3 CFU/mL to 5×10^4 CFU/mL (Olsen, 1988; p. 19). As the HRT increased, so too did the reductions of bacterial populations. *Salmonella typhimurium* was reduced by 1.3 $\log_{10}$ and *E. coli* O8 was reduced by 2.1 $\log_{10}$ after an HRT of 4.2 days using Filter A (Olsen, 1988; p. 20). *Salmonella typhimurium* was also reduced using Filter B by 1.2 and 0.8 $\log_{10}$ after an HRT of 1.4 and 1.1 days, respectively (Olsen, 1988; p. 20).

[89] Filter A had an active surface area of 80 $m^2\ m^{-3}$ and Filter B had an active surface area of 100 $m^2\ m^{-3}$ (Olsen, 1988; p. 19).

To overcome the limitations of digesting solid manure, a high temperature anaerobic digester (HSAD) was piloted at Timber Ridge Farms in Clinton, North Carolina to convert swine manure with average solids content of 24-30% into biogas (Figure 5.3).

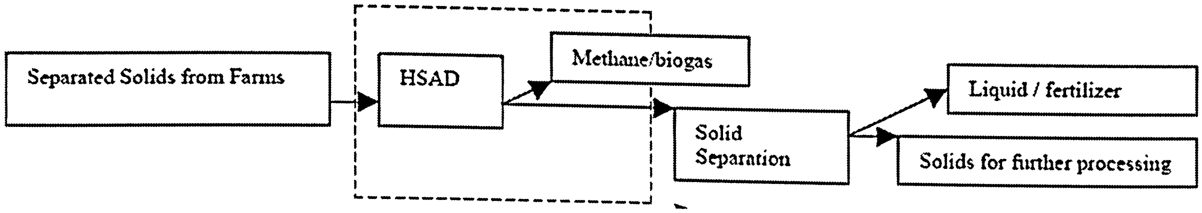

Figure 5.3: Process Flow Diagram for High Solids Anaerobic Digester (HSAD)
Source: Williams, C. M. (2004). *Development of Environmentally Superior Technologies: Phase 1 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers*. Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 17.

Approximately 75% of the swine waste was converted into biogas, while the digested substrate formed sludge suitable for land application (Zerring, 2005; p. 1; Williams, 2004; p. 17). Following a retention time of 20-30 days, *E. coli* were reduced by 4.28 log_{10}, *Salmonella* was reduced by 2.36 log_{10} and *C. perfringens* was reduced by 0.96 log_{10} in the effluent sludge (Sobsey *et al.*, 2004; p. 65). The reductions resulted in final concentrations of < 4.5, < 0.3, and 1.75×10^4 CFU/mL for *E. coli*, *Salmonella*, and *C. perfringens*, respectively (Sobsey *et al.*, 2004; p. 65). The efficacy of anaerobic digesters in removing pathogens from composted cattle manure has also been investigated. Harrison *et al.* (2005) used plug flow and continuous feed systems to evaluate the potential implications for community digesters. While the plug flow system reduced generic *E. coli* (including 0157:H7) and enterococci by 100 and 99.9%, respectively, *Mycobacterium paratuberculosis* could not be sufficiently removed (Harrison *et al.*, 2005; p. 1).[90] Initial concentrations of the pathogens were not reported by the author. In a commercial-scale application, Martin (2005; p. 7) used a plug flow mesophilic anaerobic digester to treat waste from a dairy operation in Wisconsin with a herd size of 860 cows. The manure was combined with milking centre wastewater to create a slurry prior to being transferred to the digester. The influent was determined to have an average concentration of 8.9 log_{10} CFU/100 mL

[90] *Mycobacterium paratuberculosis* is the causative agent of Johne's disease, a chronic enteritis of cattle. Protocols to prevent the introduction and spread of this pathogen are common in biosecurity programs designed to maintain herd health.

(Martin, 2005; p. 26). Following digestion, the treated liquid was land applied and the separated solids were dried and used as bedding material. After an average HRT of 29 days, fecal coliforms were reduced by 2.3 log_{10} in the effluent (Martin, 2005; p. 26). Microbial populations in the separated solids were not reported.

Low temperature anaerobic digesters have also been recently investigated for their potential to treat swine manure. Côté *et al.* (2006) suggested that pathogenic microorganisms may be effectively removed using temperatures below the mesophilic range. In laboratory-scale experiments, samples of fresh manure slurries were collected from different swine operations and digested in an enclosed sequencing batch reactor operating at 20°C.[91] Although the initial concentrations of microorganisms were highly variable in the slurries tested, *Salmonella, Giardia* and *Cryptosporidium* were reduced to undetectable levels in all samples that initially tested positive for these organisms (Côté *et al.*, 2006; p. 689). Initial *E. coli* concentrations ranged from 0 to 2.6 x 10^6 CFU/g (Côté *et al.*, 2006; p. 689). While *E. coli* were reduced to undetectable levels in only 15 of the 20 samples following digestion, reductions of 2.48 – 4.16 log_{10} were observed in the remaining samples (Côté *et al.*, 2006; p. 689).[92]

In similar experiments, Cheng *et al.* (2004; p. 2) evaluated the use of an ambient temperature anaerobic digester and nitrification biofilters to treat swine manure from a 4, 000 head sow operation. The anaerobic digester was used for the primary treatment of the swine waste and as a means of co-generating electricity and heat. The stabilized wastewater was either stored for cropland irrigation or received additional treatment using a nitrification biofilter to convert NH_4^+ to NO_3^-.[93] Following this step, the wastewater was used to recharge the manure collection pits in the pig houses, or used to fertilize and irrigate greenhouse tomatoes. *Escherichia coli, Salmonella,* and *C. perfringens* were reduced by 5.23, 4.77, and 2.84 log_{10}, respectively compared to the system influent (Sobsey *et al.*, 2004; p. 7) following the nitrifying step. Initial pathogen concentrations were not reported for this experiment.

In controlled environments, digestion can also occur under aerobic conditions. The addition of oxygen supports the growth of aerobic bacteria to degrade organic matter. Under

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[91] The Sequencing Batch Reactor (SBR) had a volume of 42 L and were intermittently fed for 20 days. The initial sludge volume at the beginning of the cycle was 21 L and was mixed for five minutes every morning by recirculating the biogas (Côté *et al.*, 2006; p. 687).

[92] Natural populations of indicator organism were reduced by 97.94 – 100% (Côté *et al.*, 2006; p. 691).

[93] HRT 12 hours (Cheng *et al.*, 2004; p. 6).

aerobic conditions, carbon dioxide, water, nitrates and sulfates are produced (San Joaquin Valley Assessment Panel, 2005). Using an aerobic fermentator operating at 55°C, Ginnivan *et al.* (1981; pp. 461-462) reduced *Salmonella dublin* in experimentally inoculated swine slurry from an initial concentration of 10^6 CFU/mL to undetectable levels in 4 hours. *Trichuris suis* and *Ascaris suum* eggs survived less than 2 hours (Ginnivan *et al.*, 1981; p. 462), although initial concentrations were not reported. Bull (2005; p. 26) also investigated the use of both aerobic and anaerobic digesters in a multi-component system designed to treat waste received from two separate swine operations totalling 9, 792 head (Figure 5.4). Wastes were flushed from the barns daily into an equalization tank, followed by a solids concentrator to separate the wastes into a sludge and liquid supernatant.[94] The sludge was treated using a mesophilic anaerobic digester maintained at 34°C +/- 3° (Bull, 2005; p. 26).

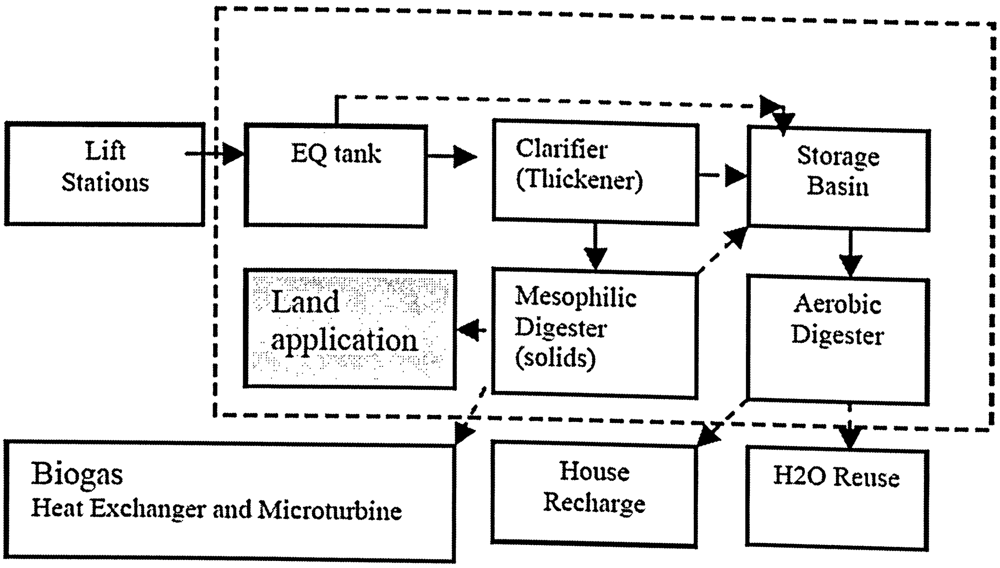

Figure 5.4: Process Flow Chart of the Recycling of Existing Nutrients, Energy and Water (RENEW) Technology

Source: Williams, C. M. (2005). *Development of Environmentally Superior Technologies: Phase 1 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers.* Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 19.

Heat was maintained by re-circulating a portion of the digester effluent through a heat exchanger. The

[94] The equalization tank ensures that the digester receives a constant flow of effluent.

biogas produced during digestion was used to heat the exchanger or used to operate a generator to provide electricity for the farm. The remaining effluent from the anaerobic digester was land applied or underwent additional treatment in an aerobic digester to facilitate nitrification.[95] The effluent from this portion of the system was used to flush the barns or further treated with a series of clarifiers to provide drinking water to the animals. Reductions in *E. coli*, *Salmonella*, and *C. perfringens* following aerobic digestion were 3.1, 1.3, and 0.6 $\log_{10}$, respectively compared to the barn flush influent (Sobsey *et al.*, 2005; p. 19). Pathogen concentrations were not significantly reduced. *Escherichia coli*, *Salmonella*, and *C. perfringens* concentrations were 1.4×10^5, 11, and 1.1×10^5 CFU/mL following digestion (Sobsey *et al.*, 2005; p. 19). However, when the effluent was treated in the water reuse component, the pathogens were reduced to undetectable levels. Reductions in *E. coli*, *Salmonella* and *C. perfringens* following water reuse treatment were > 6.5, > 2.1, and 3.9 $\log_{10}$, respectively compared to the barn flush influent (Sobsey *et al.*, 2005; p. 19).

5.7 Combined Processes – Biological and Chemical Methods for Pathogen Inactivation

As previously discussed, the increasing number of regulations imposed on farm operators has resulted in the development of treatment technologies that simultaneously address many of the concerns associated with the handling, storage and land application of manure. While the following example of commercial-scale technology involves steps to remove other contaminants, only the inactivation of notifiable waterborne pathogens (or corresponding indicator species) in manure will be discussed.

A liquid stream treatment combined with nitrogen and phosphorous removal in swine manure has been suggested as an alternative to anaerobic lagoon treatment by Vanotti *et al.* (2005a). In the multi-process treatment system (also known as "Super Soils"), solid/liquid separation is achieved by using polyacrylamide polymer and filtration mechanisms. The liquid stream is first treated with nitrifying bacteria immobilized in polymer gel pellets.[96] The inclusion of a biological nitrogen removal step prior to an alkali treatment reduces the lime dose required

[95] No microbial data was reported for this portion of the treatment system.
[96] The HRT for the swine manure following the addition of nitrifying bacteria was 31.2 h in the denitrification tank and 13.2 h in the nitrification tank (Vanotti *et al.*, 2005a; p. 212). The HRT for the swine manure following the addition of lime was 1.8 h (Vanotti *et al.*, 2005a; p. 211).

to elevate the pH since the ammonia concentration is lowered. Phosphorus removal was achieved using hydrated lime (2% $Ca(OH)_2$). The treated liquid portion of the waste stream was recycled to flush hog barns and to irrigate crops. Waste solids were separated and further processed for re-sale. A two year pilot study was conducted at the Lake Wheeler Road Field Laboratory in Raleigh, North Carolina. Manure was collected from approximately 500 pigs after accumulating for a period of 48 hours (Vanotti *et al.*, 2005a; p. 210). Collected manure was diverted into the pilot system and underwent polymer-enhanced solid-liquid separation, biological N removal and alkaline phosphorus extraction (Figure 5.5).

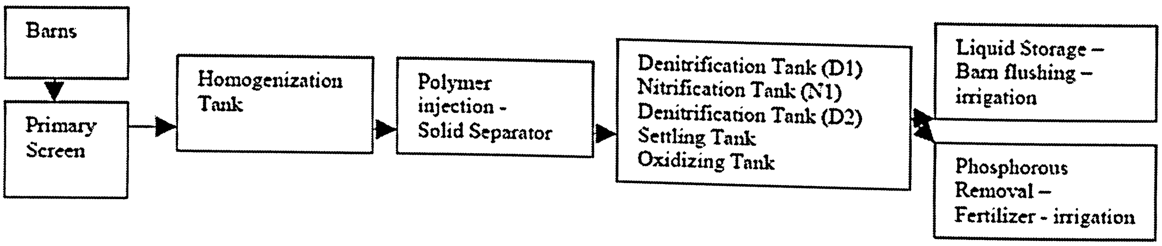

Figure 5.5: Process Flow Diagram for Super Soils technology
Source: Williams, C. M. (2004). *Development of Environmentally Superior Technologies: Phase 1 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers*. Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 19.

Samples of the swine manure were analyzed for pathogen inactivation at each step in the system. Mean concentrations of total coliforms, fecal coliforms, enterococci, and *Salmonella* in the system influent were 6.79 $\log_{10}$, 6.23 $\log_{10}$, 5.73 $\log_{10}$, and 3.89 $\log_{10}$ CFU/mL (Vanotti *et al.*, 2005a; p. 213). All pathogens under investigation were significantly reduced following the removal of nitrogen. Total coliforms, fecal coliforms, enterococci, and *Salmonella* were reduced by 4.54, 4.44, 4.10, and 2.35 $\log_{10}$, respectively in the liquid waste stream (Vanotti *et al.* 2005a; p. 213). All of the pathogens were further reduced to < 0.30 $\log_{10}$ CFU/mL following the phosphorus removal step (Vanotti *et al.* 2005a; p. 213). Average reductions for this treatment were > 6.5 $\log_{10}$ for total coliforms, > 5.9 $\log_{10}$ for fecal coliforms, > 5.4 $\log_{10}$ for enterococci, and > 3.6 $\log_{10}$ for *Salmonella* (Vanotti *et al.* 2005a; p. 213).

Following the success of the pilot study, a one-year full-scale study was conducted at a 4, 400 head finishing farm in Duplin County, North Carolina. All of the pathogens under investigation were reduced to non-detectable levels following the phosphorus removal step

(Vanotti, 2004; p. 4).[97] Pathogen removal was determined for both the liquid portion of the waste stream and the total waste stream that included untreated separated waste solids. Average reductions in the liquid portion of the waste stream for the full-scale study were 4.23 $\log_{10}$ for *Escherichia coli*, 3.42 $\log_{10}$ for *Salmonella* and 1.37 $\log_{10}$ for *Clostridium perfringens* (Sobsey *et al.*, 2004; p. 56). The final treated liquid waste effluent was reported to have average microbial concentrations of < 0.1, < 0.003, and 230 CFU/mL for *E. coli*, *Salmonella*, and *C. perfringens*, respectively (Sobsey *et al.*, 2004; p. 57). Not surprisingly, the reductions for the total waste stream were marginally lower. *Escherichia coli*, *Salmonella*, and *C. perfringens* were reduced by an average of 4.05, 3.26 and 1.29 $\log_{10}$, respectively (Sobsey *et al.*, 2004; p. 57).

The separated solids were further processed using aerobic composting under ambient temperatures ranging from 0.2 to 31.8° C (Vanotti, 2005b; p. 9). The high moisture content of the separated solids required the addition of bulking agents to decrease the density and increase porosity. Two different blends of bulking agents were tested. Blend 1 consisted of separated solids and cotton gin trash in a ratio of 1:2, while Blend 2 consisted of separated solids, cotton gin trash, and wood chips in a ratio of 1:2:4 (Vanotti, 2005b, p. 9). The solids were mechanically mixed and stored in compost bins inside an open shed for approximately 40 days.[98] The stabilized solids underwent subsequent curing in static windrows for up to 30 days (Figure 5.6).

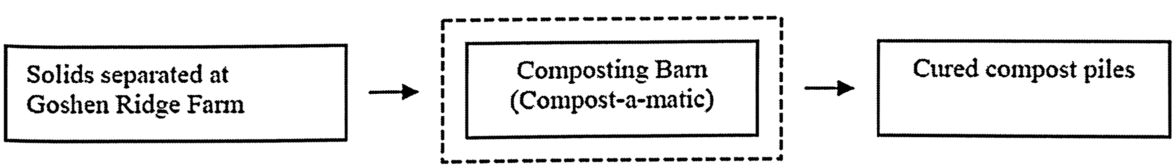

Figure 5.6: Process Flow Diagram for Super Soils Composting
Source: Williams, C. M. (2005). *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers*. Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 12.

Average compost temperatures reached > 54°C (Vanotti, 2005, p. 20). The average concentrations of *E. coli*, *Salmonella* and *C. perfringens* in the separated solids prior to

[97] Non-detectable levels is equivalent to < 10 CFU/ml (Vanotti, 2004; pg. 47).
[98] Composting bins were placed on concrete pads and measured 58.5 m long, 77.5 m wide, and 36.5 m deep (Vanotti, 2005b; pg. 12).

composting were 1.23 x 10^4 CFU/g, 0.70 CFU/g and 2.45 x 10^4 CFU/g , respectively (Sobsey *et al.*, 2005; p. 71). Surprisingly, the bulking agents were also found to contain high concentrations of pathogens. The concentrations of *E. coli*, *Salmonella* and *C. perfringens* in the wood chips were comparable to the untreated separated solids. The cotton gin trash was found to contain a lower concentration of pathogens, with average concentrations of 0.2 CFU/g and 1.58 x 10^3 CFU/g for *Salmonella* and *C. perfringens*, respectively (Sobsey *et al.*, 2005; p.71). The concentration of E. coli in the cotton gin trash was significantly higher with a value of 6.23 x 10^3 CFU/g (Sobsey *et al.*, 2005; p.71). Despite the elevated concentration of pathogens detected in the bulking agents, *E. coli* (< 1 CFU/g), *Salmonella* (< 0.003 CFU/g) and C. perfringens (< 1.73 CFU/g) were reduced to virtually undetectable levels after composting and storage (Sobsey *et al.*, 2005; p. 73). The average reduction for *Escherichia coli* and *C. perfringens* was 3.9 $\log_{10}$, while *Salmonella* was reduced by an average of 1.23 $\log_{10}$ (Sobsey *et al.*, 2005; p. 72).

5.8 Alternative Uses for Manure

As livestock operations continue to intensity, options for land disposal practices may decrease if the proportion of surrounding land available for application is lower than the amount of manure produced. The cost of using manure as a fertilizer is also susceptible to increases in marginal costs due to storage facility or transportation requirements (Zerring, 2001). Costs for these aspects have been typically low due to localized transportation needs and limited uses of constructed storage facilities. Furthermore, land application may pose a serious enough risk to human health that unconventional disposal practices should be considered. To overcome these limitations, there is a growing market dedicated to using manure as an alternative medium for a variety of products and services (Table 5.4).

Table 5.4: Emerging Technologies for Animal Waste Applications

Technology	Process
Algae Production	Nutrients in animal waste used to produce algae and photosynthetic bacteria Product is used as a fertilizer
Aquaculture	Low cost alternative to high-protein feed
Bedding or Litter	Processed into a solid used as bedding or litter
Building Material	Processed into fiberboard for construction related activities Recommended uses include sheds, barns and outdoor structures
Mushroom Cultivation	Used in commercial mushroom production
Nursery Pots	Compressed into pots after solids/liquid separation Product releases nutrients over time
Sealing Ponds and Dam	Multi layer application to seal ponds and dams Used in concert with organic matter and soil to create an impermeable membrane
Soil Reclamation	Remediation of soils contaminated with oil or salt Used to re-establish areas disturbed by excavation activities

Generated from: United States Environmental Protection Agency. (2002a). *Alternative Technologies/Uses for Manure - Draft* (EPA 68/99-253). Washington, DC: Author.

Admittedly, alternative uses for manure are not commonly employed and as such, little information is available on their performance. There are two possible alternatives to land application of manure and include conversion into value-added products and conversion into energy sources. As demonstrated by the treatment processes of composting and digestion, manure can be converted to value-added products and/or can be used as an energy source. Value-added products include fertilizers, soil amendments, or feed additives. Through methods of combustion, and chemical and biological conversion, manure can be used for on-farm purposes or can be sold to power distributors. Although the review of these alternatives is beyond the scope of the current study, they demonstrate the potential to reduce pathogenic loading in source water and may warrant discussion in future investigations of this nature.

5.9 Summary

Given that pathogen reduction in animal manure has been a secondary consideration to nutrient stabilization, volume reduction, and temporary storage benefits, many technologies designed to address pathogens have not been tested at the commercial level. Comparing treatment processes is also cumbersome due to limitations in detection and enumeration where the level of pathogen inactivation is often inferred based on the use of indicator species. For instance, the inactivation of *Ascaris* and *C. perfringens* suggests that other highly resistant pathogens such as *Cryptosporidium* and *Giardia* may be inactivated under similar conditions. In addition, a number of treatments reviewed as part of this study employed the use of different technologies as part of a larger system to remove other contaminants such as nitrogen and phosphorous. The untreated separated solids were land-applied, while the treated liquids were used to flush barns, irrigate greenhouse crops and provide drinking water to animals. These technologies significantly reduced pathogen loads in the liquid waste stream, but failed to address pathogen loads in the separated solids intended for land application.

Despite the limitations of the data, some general conclusions can be reached. Although UV treatment is considered to be a safer alternative to chemical forms of disinfection, the presence of suspended solids and dissolved organic compounds severely limits the efficacy of this treatment method. Other physical methods of inactivation, such as the study of direct temperature changes on animal wastes have resulted in significant reductions in highly resistant microbes. Extreme cold has been effective in killing *Cryptosporidium* oocysts extracted from cattle manure, while extreme heat has been effective in killing oocysts in swine slurry. Despite the success of these treatments, testing has been fairly limited to laboratory-scale studies. While the use of chemical disinfection may improve soil conditions due to changes in pH, it fails to adequately destroy many of those pathogens that are the most persistent in the environment. Furthermore, due to the high costs associated with chemicals, many compounds are not evaluated at the farm-scale. For instance, gassing of chicken manure using ammonium sulphate and potassium hydroxide was extremely effective in eliminating *E. coli*, *S. typhimurium* and *L. monocytogenes* from chicken manure in laboratory-scale studies. However, the amount of ammonia required to achieve the same results in the field would be a large quantity. For example, under field conditions 10 kg of ammonia would be required per tonne of chicken manure to match the level of effectiveness obtained under laboratory conditions. The use of quicklime to increase pH and temperature of chicken manure was also effective in killing *Ascaris* eggs in swine slaughterhouse sludge. The study suggests the potential application to protozoan pathogens such as *Giardia* and *Cryptosporidium,* but further investigation at the field-scale is required. Other technologies, such as the use of plant-derived oils, have also demonstrated inactivation potential of fecal coliforms in cattle manure slurry. Again, these results have only been obtained in laboratory-scale experiments.

Biological treatment processes demonstrated the greatest capacity for the inactivation of both protozoan and bacterial pathogens. Constructed wetlands proved to be effective in removing bacterial pathogens from chicken litter and swine wastewater, but only when used in combination with other primary treatment technologies. When material high in organic matter, such as manure, is introduced into the system, the Biological Oxygen Demand can not be removed. As a result, the chemical and biological processes responsible for contaminant removal are inhibited. When used in combination with other treatments such as anaerobic lagoons or physical separators, constructed wetlands are significantly more effective in eliminating bacterial pathogens. For instance, *Escherichia coli*, *Salmonella* and *C. perfringens* were significantly reduced in the liquid portion of the waste stream when a mechanical solids separator was used prior to treatment in the constructed wetland. *Escherichia coli* and *Salmonella* were reduced by 4.63 and 2.9 $\log_{10}$, respectively in swine waste water. Compared to other treatments reviewed, the constructed wetland was the most effective in reducing *C. perfringens*. The average reduction of *C. perfringens* was 4.1 $\log_{10}$. The concentration of these pathogens, however, remained considerably high in the untreated solids. Given the potential requirements for large parcels of land to support constructed wetlands, this treatment option may not be applicable to all farm operators.

In waste streams intended for land application, digesters have been commonly used. Due to differences in temperature, HRT, loading rates, and mixing conditions, results are highly variable, although many systems have undergone testing at the farm-level. Ambient temperature anaerobic digestion has proven to significantly reduce *E. coli* and *Salmonella* in swine manure. Average reductions of 5.23 and 4.77 $\log_{10}$ where achieved for *E. coli* and *Salmonella*, respectively in a 4, 000 head sow operation. *Clostridium perfringens* was also reduced by 2.84 log using this treatment. The successful application of ambient digestion makes this treatment option a practical solution for farms operating under cold weather conditions. Anaerobic digestion conducted at the thermophilic temperature range has also been successful in treating swine manure. *E. coli*, *Salmonella* and *C. perfringens* were reduced by 4.28, 2.36 and 2.84 $\log_{10}$, respectively at a centralized swine manure collection facility.

Few treatments have evaluated the potential to reduce pathogens in cattle manure. Composting treatments have consistently reduced bacterial pathogens in cattle manure in pilot experiments, but have not translated well to the field. This may be largely due to exposure to ambient temperatures and difficulty in determining windrow temperatures. The selection of bulking agents can also influence the efficacy of a composting system. Many bulking agents contain concentrations of pathogens that are higher than those found in the material intended for composting. Furthermore, finished compost is susceptible to pathogen re-growth and must be considered in the development of a treatment program. Despite these limitations, the most successful treatment option for the removal of *E. coli* from this waste stream has been the use of mesophilic composting. Average reductions of 4.28 $\log_{10}$ have been achieved at the commercial level using this process. Thermophilic composting has also been effective in reducing *Salmonella* and *C. perfringens* in swine manure. Average reductions of 3.9 $\log_{10}$ have been achieved at the commercial level using this process for both *Salmonella* and *C. perfringens.* Composting experiments have also brought attention to the use of indigenous microorganisms to inhibit the growth of pathogens by way of inhibitory compounds, secondary metabolites, cell lyses, or nutrient exhaustion although the reliability of inhibition is not yet established.

Among the technologies considered as part of this review, those that were designed to treat more than one specific microbial contaminant were found to be the most effective. The "Super Soils Technology" removed pathogens from the total waste stream by using a combination of nitrogen and phosphorous removal processes for the liquid fraction and composting for the solid fraction in swine manure. Average reductions in the liquid fraction of the waste stream for the full-scale study were 4.23 $\log_{10}$ for *Escherichia coli*, 3.42 $\log_{10}$ for *Salmonella* and 1.37 $\log_{10}$ for *Clostridium perfringens.* The final treated liquid waste effluent was reported to have average microbial concentrations of < 0.1, < 0.003 and 230 CFU/mL for *E. coli*, *Salmonella* and *C. perfringens*, respectively. Although the reductions for the total waste stream were marginally lower, *Escherichia coli*, *Salmonella* and *C. perfringens* were reduced by an average of 4.05, 3.26 and 1.29 $\log_{10}$, respectively. Final concentrations of *E. coli* (< 1 CFU/g), *Salmonella* (< 0.003 CFU/g) and C. perfringens (< 1.73 CFU/g) were reduced to virtually undetectable levels after composting and storage.

As expected, the lack of controlled studies conducted at the commercial-scale is an obstacle in determining which technologies provide the greatest level of pathogenic reduction. Furthermore, few studies address those pathogens which display both prevalence and persistence in animal manure. For example, most studies conducted on swine manure concentrate on removing the most prevalent pathogen, *Salmonella*. Since manure-related human epidemics have been attributed to those pathogens that are capable of survival for prolonged periods of time, rather than those that are the most prevalent, studies conducted on swine manure must give greater attention to *Giardia* and *Cryptosporidium*. And although studies conducted on cattle manure have focused on the removal of *E. coli*, *Cryptosporidium* is not addressed despite displaying both prevalence and persistence. This clearly demonstrates that future investigations of manure treatment methods should re-evaluate which pathogens need to be addressed in order to prevent risks to human health.

CHAPTER SIX: APPLYING THE BIOSECURITY MODEL

6.1 Developing Biosecurity Policies – Making the Case for Source Water Protection

While biosecurity measures have typically played an important role in livestock health and the safety and security of animal products, little attention has been given to its potential in protecting the environment. A more recent definition of biosecurity, as proposed by O'Bryen and Lee (2003; p. 275) acknowledges this broader scope and reads: "Biosecurity is an essential group of tools for the prevention, control, and eradication of infectious diseases and the protection of human, animal, and environmental health." Given that biosecurity may also relate to bioterrorism, agro-terrorism, and fouling organisms, Scarfe (2003) suggests that at its broadest level, biosecurity may be defined as the protection against the introduction of adverse biological events. Adverse biological events could include the introduction of quarantined pests, invasive alien species, modified organisms (Meyerson *et al.*, 2002), and ecological impacts (Scarfe, 2003) such as the contamination of soil, air, and water.

Given that the intent of source water protection is to keep raw water as clean as possible, biosecurity programs may be a useful instrument for protecting source water from pathogenic contamination in agricultural operations. The jurisdictional review conducted in Chapter 2 revealed that both conceptual and structural biosecurity is already an implicit component in local and regional water policy. For instance, the *Nutrient Management Act* (2002) outlines the requirements for livestock operators to facilitate better planning of operations to avoid impacts to source water quality. The establishment of protocols for facility siting and animal waste storage structures by the Act are comparable to conceptual and structural biosecurity measures that are designed to control and eradicate disease in livestock. However, an investigation of the pathogen abatement effects of these protocols by Stiefelmeyer (2003) determined that the *Nutrient Management Act* would not be effective in managing pathogens. In a more recent review of international governance for drinking water, Kelly (2005) found that the majority of regulations have undergone similar changes such as the implementation of monitoring regimes at the source, updating allowable concentrations of pathogenic contaminants, and strengthening the operation of treatment facilities.

The protection of drinking water prior to entering treatment and distribution systems may be accomplished through the use of operational biosecurity measures. Measures to prevent pathogenic loadings in source water could be developed using existing biosecurity programs for disease control in livestock as a model. A controlled approach to manure treatment prior to land application and storage may be substituted for quarantine, sanitation, and hygienic measures that have proven to be effective within the traditional framework of biosecurity programs (Figure 6.1).

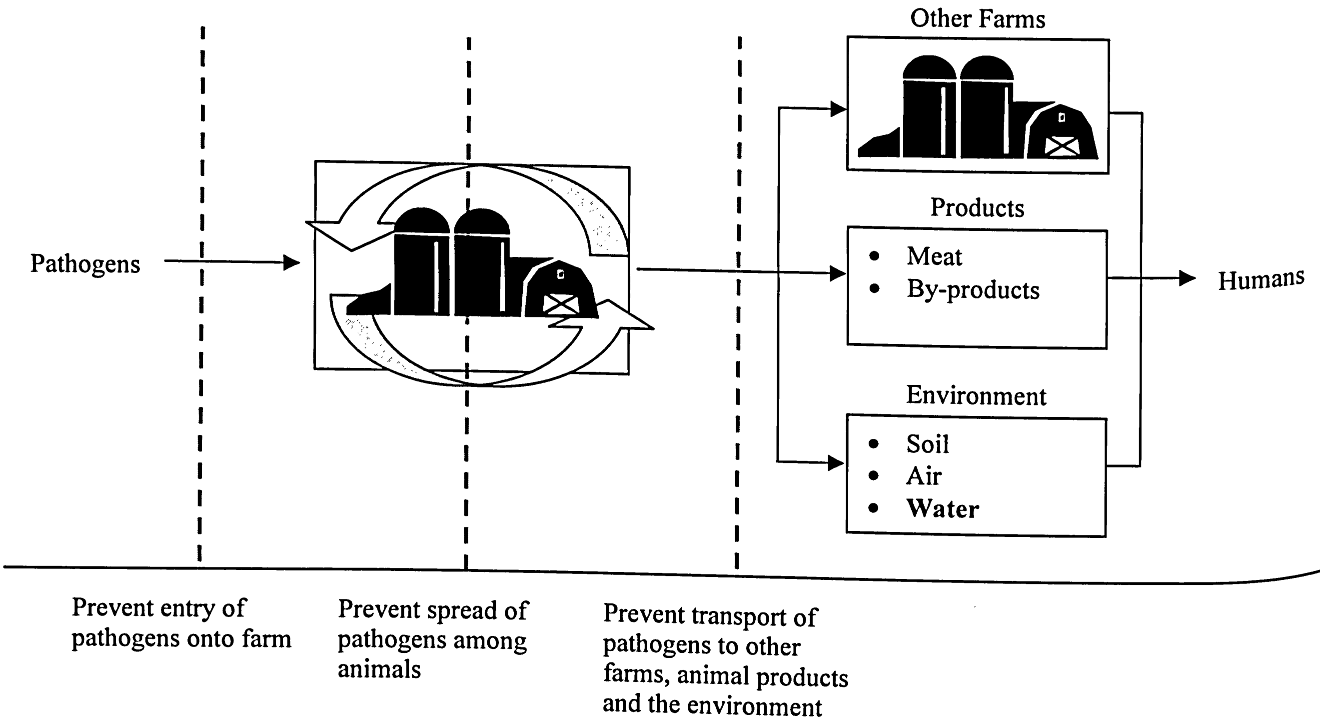

Figure 6.1 Environmental Farm-Level Biosecurity

The extent to which conceptual, structural, and operational levels of biosecurity are applied depends on a number of factors. These factors include funding and the availability of physical and personnel resources (Shane, 1995). The overall approach taken in managing agricultural operations is also an important consideration. Well-informed operators are more likely to be able to monitor and modify their programs when necessary (Rossiter and Burhans, 1996). Morris (1995) also suggests that the rationale for the establishment of a biosecurity program must be clearly communicated between management and personnel. Furthermore, a strong commitment from personnel responsible for carrying out day-to-day biosecurity procedures is critical to achieving and maintaining the expected goal(s) of the program (Lee and

Bullis, 2003; Pruder, 2004). Although day-to-day activities at the operational level can directly affect the efficacy of a biosecurity program, stakeholders may indirectly impact a program. Owners, operators, and investors equally share in the responsibility for ensuring that the anticipated benefits from a biosecurity program are obtained (Lee and Bullis, 2003). Livestock operators may, however, be apprehensive in implementing biosecurity programs given that incentives may be limited, or non-existent. This type of communication is becoming increasingly important as livestock operations continue to intensify and the number of stakeholders increases. Despite a broad range of prospective applications, Scarfe (2003) suggests that biosecurity policies are linked by the following elements:

1. Science-based decision making;
2. Economic and socio-political rationales;
3. Standardized and uniform methodology;
4. Relative ease of application;
5. Transparency;
6. Consistent delivery;
7. Consistent enforcement; and
8. Focus on prevention.

6.1.1 Science-Based Decision Making

The conclusions drawn from sound scientific research have the potential to be powerful instruments in the formulation of legislation and management regimes. Many policies and programs, however, lack the scientific evidence necessary to justify the measures used to prevent pathogenic contamination of source water. A jurisdictional review was conducted by The Technical Experts Pathogen Sub-Committee on Source Water Protection to determine how Canadian provinces and other countries control pathogenic contamination of source water supplies. Many of the legislative requirements in other jurisdictions were found to be based on best management practices supported by little empirical evidence. Gostin *et al.* (2000) reviewed the laws, regulations, and policies that currently govern the protection of drinking water supplies in the United States and found that regulatory frameworks were fraught with conflicts where the management of *Cryptosporidium* was concerned. A similar review conducted by Stiefelmeyer (2003) suggests that even the regulatory framework of the *Nutrient Management Act* (2002) fails to adequately manage pathogens despite having originally implied that pathogen reduction would be an outcome. These findings imply that current policies have left sources of drinking water vulnerable to pathogenic contamination.

To overcome this limitation, regulators need to place a greater emphasis on defendable science-based policy. As such, it is imperative that policies are constantly reviewed and revised as new information becomes available (Scarfe, 2003). In addition, the efficacy of proposed measures must be tested at the field-scale before they can be prescribed. Failure to validate the level of anticipated protection can result in either the expenditure of funds on unnecessary biosecurity measures, or economically devastating disease outbreaks (Amas and Clark, 1999). For a review of the estimated levels of pathogenic reduction achieved by currently available technology the reader is referred to Section 5.3.

6.1.2 Economic Rationale

Perhaps the most significant and well accepted element of any policy is its economic feasibility. The resources and efforts invested in producing or revising regulations will only hold value if they are properly implemented and adequate funding is available. In many commercial livestock operations, biosecurity programs are designed to maximize profit by preventing disease introduction. Determining the cost effectiveness of implementing prevention and control measures can be projected by comparing the annual costs of the biosecurity program to the economic loss that may arise during a disease outbreak among livestock (Shane, 1995). Improved quality or increased volume of production may also be considered when evaluating the expenditure of money and resources (Morris, 1995). Despite the success achieved in the poultry industry, there is still considerable opportunity for improvement especially where contract production is employed.[99] Due to the fixed costs associated with this arrangement, market conditions can influence operational practices. When market demand is high, it is more profitable for both the grower and integrator to increase stock density and decrease stocking intervals (Morris, 1995). In efforts to maximize production, and subsequently profit, disease prevention practices are often neglected.

[99] In contract production, an integrator (owner) contracts a portion of production activities out to smaller operators at a fixed cost. Facility operators raise the animals while the integrator processes and sells the final product (Zilberman *et al.*, 2001).

In addition, biosecurity programs must consider the impacts to operators in terms of practicality and cost-effectiveness. Often, operational measures dictate the overall cost of a biosecurity program (Lee and Bullis, 2003). The investment made in establishing a biosecurity program should not exceed the potential return from reducing the impact of the disease (Morris, 1995). These returns ultimately depend on the value of the animal that is being protected (Lee and Bullis, 2003) or natural resources such as water. Economic and social responses, as well as the overall acceptance of biosecurity policies is heavily dependent on how the value of ecosystems and human health are characterized (Scarfe, 2003). The commercial value of ecosystem services and resources is not, however, as easily quantified. Contamination of municipal drinking water supplies in Walkerton required the provincial government to incur significant expenses for legal action and health care. If the livestock operation suspected to be the source of contamination had been managed using a program to adequately prevent pathogenic loadings of source water, the potential returns would have been high in this situation.

6.1.3 Standardized Methodology and Ease of Application

The use of standardized biosecurity protocols is encouraged to ensure consistent results in the control and eradication of disease. However, given the unique characteristics among livestock operations, the development and implementation of biosecurity programs must be designed on an individual basis. As such, it becomes necessary to provide options to accommodate these differences. Rossiter and Burhans (1996) also note that inconsistencies in resources such as management, labour, and finances make establishing a single control formula impossible.[100] While the effectiveness of a single control formula is limited, Bowes (2005) suggests that adopting standards of practice which are quantifiable can lead to the success of an industry-wide program. For the purposes of source water protection, measurable targets, such as log reductions of pathogen concentrations, could be used to determine the efficacy of a treatment system.[101] This approach is easily transferable to policy and may reduce monitoring and compliance requirements for governing bodies.

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[100] This statement is in reference to Johne's Disease, but is applied in a general context for the purposes of this discussion.

[101] Log reductions have only been established for protozoan pathogens in water at the point at w hich it is delivered to the first consumer. See Section 2.0 for more information.

6.1.4 Consistent Delivery and Transparency

As the definition of biosecurity expands to include other areas of impact, regulators must play a critical role in the successful application of programs. The most effective biosecurity strategies are harmonized within and between varying levels of governance (Scarfe, 2003). Consistent delivery is also reflected in how roles and responsibilities are communicated to stakeholders. Shane (1996) suggests that a large part of establishing effective operational biosecurity programs is through educational programs for farm operators and their employees to distinguish their role in minimizing the risk of disease. Similarly, governing bodies need to develop communication strategies for operators affected by changes in existing legislation, and when new legislation is introduced. A considerable amount of confusion has resulted from a lack of clear communication regarding the availability of funding for farm operations. While a significant number of Agricultural Interest Groups and individual farmers support the *Nutrient Management Act*, the delivery of information and approach to its implementation has been highly criticized.

6.1.5 Enforcement

Enforcement programs rely heavily on the availability of both human and financial resources. Due to limited availability of resources, incentive-based programs may be an option for ensuring compliance with biosecurity strategies. Alternatively, compliance could be imposed through industry, rather than a regulatory agency. O'Bryen and Lee (2003) suggest that producers be monitored for their compliance with industry-established protocols through a licensing or certification body. Under the *Farm Products Marking Act* (1990), the Farm Products Marketing Commission (FPMC) has been delegated the power to set up and supervise marketing boards.[102] Marketing boards established under the Act address a wide range of commodities including livestock and are largely comprised of owners and operators. For instance, Ontario Pork has been granted the legal right to control the marketing and transportation of market hogs produced in Ontario.[103] The Board requires all producers to sell market hogs through the Board. Producers are charged a service fee for every market hog sold in Ontario (Ontario Pork, 2005).

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[102] *Farm Products Marketing Act*, R.S.O. 1990, c. F.19, s. 3(1).
[103] R.R.O. 1990, Regulation 419, s. 2 and R.R.O. 1990, Regulation 420, s. 1.

In a similar capacity, the Dairy Farmers of Ontario ([DFO], 2005) ensure that producers, transporters, and milk graders comply with provincial regulations and DFO policies.[104] Farm inspections are conducted by DFO once every two years in order to determine the classification of the farm.[105] The intent of the classification program is to market milk that originates from operations where the farm premises, milking equipment, and surroundings meet a number of conditions. These conditions include (a) biosecurity measures to ensure that contaminants that could affect animal health or milk quality cannot be transferred from one farm to the next, (b) milk contact surface cleanliness to ensure milk contact surfaces are clean, (c) milk cooling to ensure milk is cooled efficiently, (d) udder contact surfaces to ensure that udder contact surfaces are clean, and (e) physical structures to ensure that physical structures are clean and tidy and in good repair. Operations that repeatedly fail to meet these conditions may be shut-off from the market.

While there are no permitting or licensing requirements to operate a livestock production facility in Ontario, the role of commodity marketing boards could be expanded for the purpose of administrating compliance with source water protection. As demonstrated by the Dairy Farmers of Ontario, the framework for monitoring biosecurity programs is already in place.

6.1.6 Focus on Prevention

For biosecurity programs designed to prevent contagious diseases in animals, emphasis is placed on proactive measures. For disease control based on prevention, strong management practices, and an understanding of the biology of the disease can contribute to a successful biosecurity program (Rossiter and Burhans, 1996). In some biosecurity programs, vaccination and preventative medication (Morris, 1995) are used to provide an additional level of protection against disease infection. There is some debate that actions falling outside of the scope of biosecurity may be equally effective in controlling disease. For instance, nutrition (Bicudo and Goyal, 2003) and selective breeding for disease resistance (Pruder, 2004) have also been shown to be effective tools for disease prevention.

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[104] The quality of raw milk is established through routine testing conducted by the University of Guelph. Producers who do not meet minimum quality standards are subject to financial penalties (Dairy Farmers of Ontario [DFO], 2005).

[105] Farm inspections are conducted more frequently for operations that fail to meet quality standards (DFO, 2005).

Focusing on prevention alone may not, however, offer the greatest level of protection. Biosecurity policies should also be developed keeping control, management, and eradication procedures in mind (Scarfe, 2003). Measures to control pathogens after infection has been established, (such as antibiotic therapy or quarantining affected animals) are also critical components in a biosecurity program should the first line of defence fail. This is the underlying concept of the multi-barrier approach used in Ontario's Strategy for Safe Drinking Water. Despite the wide spread acceptance of the multi-barrier approach, the development of drinking water legislation has primarily been based on response rather than prevention.

6.2 Integrating Biosecurity Strategies with the *Clean Water Act*

The proposed implementation framework for the *Clean Water Act* is based on a phased approach that begins with the identification and characterization of significant drinking water threats using science-based risk assessments (Appendix 2.6). The Ministry of the Environment is optimistic that the public disclosure of information obtained through the source protection planning process will encourage property owners, businesses, and farmers participating in activities that threaten drinking water quality to take voluntary action to reduce risks. In cases where existing programs and policies can not adequately protect sources of drinking water, the Act provides municipalities with the authority to regulate significant threats through a permitting process. The number of activities subject to the permitting process will largely depend on the definition of "significant". A "significant" drinking water threat is defined in Bill 43 as a threat that, according to a risk assessment, poses or has the potential to pose a significant risk.[106] Unfortunately, this definition fails to further address what constitutes a "significant risk". In an effort to advise the Minster of the Environment on the threats assessment framework for source water protection planning, the Watershed-Based Technical Experts Committee (2004; p. xv) defined a significant risk to be "one that has a high likelihood of resulting in adverse human health effects [via]: (a) rendering a current or future drinking water source impaired, unusable, or unsustainable, or (b) compromising the effectiveness of a drinking water treatment process". Given the likelihood that the acquisition of reliable data may prove to be difficult, the Watershed-based Technical Experts Committee (2004) also recommended that a semi-quantitative approach (based on the characteristics of the threat, the pathway from the

[106] Bill 43, 2005, 2nd Session, 38th Legislature, s. 2(1).

contaminant source to drinking water, and the human population consuming the water) be used to categorize risks. Although the proposed methodology for the preparation of risk assessments is not specified in Bill 43, the Ministry of the Environment intends to provide guidance on the technical and scientific work needed to prepare a risk assessment report. The work plan for the risk assessment would be outlined in the Terms of Reference which would be subject to approval before the source protection planning process could be initiated.

Once drinking water threats are prioritized, the source protection plan would address how significant threats could be managed. Surprisingly, the Ontario Ministry of the Environment (2006d) advocates the use of Best Management Practices to adequately address risks posed by farming activities in areas that have been designated as vulnerable drinking water sources. Given the standardized nature of Best Management Practices, this guidance is contrary to the mandate of the Act which seeks to protect source water based on local issues. Only if the risk is still considered to be significant after the application of BMPs and other regulatory requirements, would further action be taken. The conditions of the permit may go beyond provincial nutrient plans and would require site-specific mitigative measures. For instance, risk management plans could address threats due to nutrient management practices on farms that are not covered under O. Regulation 267/03.[107] It is important to note that the municipality can not request that property owners, businesses, or farmers to submit a risk management plan until the risk assessment report has been approved. This approach will avoid unnecessary expenditures of human and financial resources in attempting to manage insignificant risks in intake and wellhead protection zones.

Limiting the development of risk management plans to activities in intake protection zones and wellhead protection areas may not, however, provide adequate protection against those threats designated in the source protection plan. For instance, spill events or run-off that occurs outside of surface water intake protection areas are still capable of causing contamination. While the contamination of surface water outside of intake protection areas allows for a greater response time, it nevertheless still contributes to impaired quality of raw water. In addition, care must be taken to avoid over-prescribing the use of risk management plans in an attempt to gain

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[107] The provision that provides the most protection to drinking water quality or quantity prevails if there is a conflict between a provision of the *Clean Water Act* and the provision of another act or a regulation made under another act (Bill 43, 2005, Part III – Effect of Source Protection Plans).

an additional level of protection. The United States Environmental Protection Agency's decision to expand the minimum requirements for Concentrated Animal Feeding Operations (CAFOs) permits granted under the National Pollutant Discharge Elimination System resulted in the filing of numerous petitions for judicial review. As a result, the US EPA is currently seeking comment on the proposed revisions for the program.

Risk management plans under the Ontario's *Clean Water Act* will ultimately contain provisions on how to mitigate threats to vulnerable sources of water. The mitigative measures prescribed under the risk management plan could include biosecurity strategies that employ the use of manure treatment technologies to protect source water from pathogenic contamination in vulnerable areas. Operational biosecurity strategies considered as part of the risk management plan would complement existing by-laws and regulations that already address conceptual and structural requirements for those farms that pose significant threats to drinking water quality. Given that the onus for development of the risk management plan may lie with property owners, businesses, and farmers, information regarding the applicability of these technologies must be readily available to assist in the development of effective risk management plans. The selection of these technologies is likely to be a critical step in the development of risk management plans. Unfortunately, the availability of scientific evidence to support the efficacy of manure treatment technologies at the commercial-scale is limited. This lack of evidence will be a significant obstacle in the development of risk management plans for agricultural operations and will no doubt impede the overall progress of the *Clean Water Act*. As such, it is imperative that the province recognize the need to address the lack of available technology to support risk management plans.

Admittedly, the selection of a preferred treatment technology can not rely solely on the level of pathogenic reduction that can be achieved in manure. There are a number of factors that affect the selection of manure treatment technologies that should be considered prior to implementation (Table 6.1).

Table 6.1: Factors to Consider When Evaluating and Selecting a Manure Treatment Approach

Factor	Comment
Approach applicability	Evaluated on basis of past performance, reliability, complexity, data from full-scale plants, published research, pilot-scale plants
Manure production rate and variability	Some treatment processes are not compatible with all rates
Manure characteristics	Affects the types of processes that are most effective and the requirements for appropriate operation
Inhibiting and unaffected constituents	Some constituents may be inhibitory to processes; some constituents may be unaffected by treatment
Climatic constraints	Temperature affects the rate of reaction of most chemical and biological processes and may affect physical processes as well; warm temperatures may accelerate odour generation and inhibit atmospheric dispersion
Treatment residuals	Types and amounts of solid, liquid, and gaseous residuals produced during treatment; how these residuals will be further treated or disposed of
Environmental constraints	Geological, hydrological, prevailing winds, and proximity to residential areas may restrict or affect the use of certain processes; process noise and traffic may also affect site selection
Energy requirements	Energy requirements and projects future energy costs should be considered for cost-effect designs
Personnel requirements	Number and skill level of workers; training
Operation and maintenance	Special operating and maintenance requirements should be considered, as well as spare parts availability and cost
Compatibility and adaptability	Some unit processes may be better suited to existing processes than others; prepare for future changes
Economic life-cycle analysis	Consider initial and long term operating and maintenance costs – the system with the lowest initial costs may have the highest operation and maintenance costs; sources of available funding may also affect process selection
Land availability	Sufficient space to accommodate current facilities; room for future expansion; buffer areas to minimize visual, noise, odour impacts

From: Robbins, J.H. (2005). *Understanding Alternative Technologies for Animal Waste Treatment: A Citizen's Guide to Manure Management.* Tarrytown, NY: Waterkeeper Alliance; p. 19.

As energy demands in Ontario continue to rise and as agricultural areas face increasing pressures of urban sprawl, energy requirements, and land availability each treatment option should be carefully examined. Climatic constraints are also important given the seasonal changes experienced in Ontario. Furthermore, variability in livestock operations and manure production rates can significantly impact the efficacy of the treatment method. The magnitude of treatment options used for Concentrated Animal Feeding Operations defined under US legislation may not translate well to smaller operations in Ontario. In order to fully ascertain the appropriateness of the treatment, the technology must be evaluated using controlled, replicated studies conducted at the commercial-scale. The selection of the treatment alternative should also be subject to cost-benefit analysis to ensure that the selected method meets the objectives for its intended use.

While funds have been allocated to scientific studies and other planning costs, a mechanism for the allocation of funding to implement source water protection plans has not yet been established. Amendments to compliance dates, general lack of financial resources, and poorly delivered information under the *Nutrient Management Act* (2002) resulted in funding controversies and opposition to the legislation. To avoid a similar outcome during the implementation of risk management plans, funding mechanisms made under the *Clean Water Act* must be publicly introduced early on to identify any inconsistencies. Cost effectiveness will also be a critical factor in determining how risks are to be managed. Imposing pathogen reduction programs, such as operational biosecurity measures, could overwhelm already financially burdened farming operations. In recognition of this possibility, the Ontario Ministry of the Environment (2006c) suggests that it may be more cost-effective to relocate a municipal well than require property owners to apply risk management measures.

6.3 Estimated Costs

To adequately address the research objectives identified in Chapter One, the cost per unit will be determined for the methods of pathogen inactivation identified through the review of manure treatment technologies that provide the greatest level of pathogen inactivation. While a number of technologies have been shown to effectively removed pathogens from livestock waste streams, this review revealed that mesophilic composting of cattle manure and the application of the Super Soils Technology to swine manure demonstrate the greatest potential for pathogen removal. The intended goal of this exercise is to demonstrate the cost-effectiveness of the manure treatment technology. Although a cost-benefit analysis would provide a more detailed account of the advantages and disadvantages of a preferred treatment strategy, it is beyond the scope of this study.

6.3.1 Super Soils Technology

The Super Soils Technology was comprised of 2 phases. The first phase involved a multi-process treatment system involving solid/liquid separation, followed by nitrogen and phosphorous removal in the liquid fraction of the waste stream. Six barns were located on site. Each barn had two pits that were emptied and recharged once a week. The effluent from the pits was pumped to a homogenization tank prior to treatment. On-farm treatment is divided into several components. Costs for each component were standardized for a 4 320 head feeder-to-finish hog farm (Appendix 6.1.1 – 6.1.12). The estimated cost was $453.58 per 1 000 pounds of Steady State Live Weight (SSLW) of hogs per year (Table 6.3).[108]

Table 6.2: Standardized Costs for Super Soils Technology (On-Farm) per Year

Component	Cost/1, 000 lbs SSLW[1]	Cost/Head[2]
Manure Evacuation and Lift Station	$13.64	$1.84
Strainer	$0.48	$0.06
Homogenization Tank	$30.92	$4.17
Separation Building	$22.32	$3.01
Solids Separator	$136.02	$18.36
Observation Deck	$4.69	$0.63
Denitrification Tank	$20.07	$2.71
Nitrification Tank	$92.09	$12.43
Settling Tank	$18.83	$2.54
Clean Water Tank	$9.49	$1.28
Phosphorous Removal	$45.06	$6.08
Return to Barns	$2.31	$0.31
Royalty Fees	$23.54	$3.18
Increased Land Application Cost	$34.11	$4.61
Total Cost	**$453.57**	**$61.23**

1. Source: Task 1 Team. (2005).Technology report: Super Soils on-farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 1
2. Based on average animal SSLW of 135 lbs.

On a per animal basis, this phase of the treatment amounted to $61.23 per year (Table 6.2). The second phase involved the aerobic decomposition of the organic materials found in the solid fraction of the waste stream. The composting facility was built off site from the first phase and is intended to accommodate the receipt of separated solids from other farms. Costs for this phase of the technology were categorized by construction and maintenance expenditures for both the composting building and the equipment utilized. Costs for each component were standardized for a composting facility operating with 5 bins (Appendix 6.2.1 – 6.2.2). The predicted standardized cost for the composting building and equipment is anticipated to be

[108] Assumes total Steady State Live Weight of 583 200 lbs (Task Team 1, 2005; pg. 14).

$342 315.08 and $21 219.34, respectively (Task 1 Team, 2006; p. 23). The amount of manure produced affects the standardized costs of the composting facility (Table 6.3).

Table 6.3: Effect of Manure Production on Standardized Costs for Super Soils Technology Composting per Year

Level of Manure Production	# Head Needed to Produce 10 880 Wet lbs. of Solids/Day[2]	Predicted Cost/ 1 000 lbs SSLW	Cost/Head[3]
Low Production 4 094 lbs. of separated solids/day/farm	9 133	$73.78	$9.96
Medium Production 14 661 lbs. of separated solids/day/farm	3 206	$210.19	$28.38
High Production 19 960 lbs. of separated solids/day/farm	2 355	$286.18	$38.63

1. Generated from: Task 1 Team. (2005).Technology report: Super Soils on-farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 25.
2. 10, 880 wet lbs./ day of separated solids are needed as feedstock to operate the standardized Super Soils composting facility at full capacity.
3. Based on average animal SSLW of 135 lbs.

Assuming a low manure production value, the cost per head amounts to $9.93 per year. Combined with the costs incurred for the first phase of this technology, the cost/head/year amounts to $71.19.

6.3.2 Mesophilic Composting

The mesophilic composting process involved the placement of manure in windrow piles on a concrete pad in a composting facility. The manure was exposed to ambient temperatures, but was protected from precipitation. Costs provided are based on a separate case-study conducted on a dairy farm with 550 head of cattle using the same technology producing an average of 9 000 m^3 of waste annually (Table 6.4). Operating costs are based on labour, fuel, and electricity. Equipment, pad, and building costs are based on repair and maintenance, interest, and depreciation.

Table 6.4: Annual Expenses for Windrow Composting with Pull-Type Turner on Asphalt Pad with Roof

Component	**Annual Cost/ 9 000 m^3 waste**	**Annual Cost/Head[1]**
Operating Costs	$5 815	$10.40
Equipment	$24 750	$0.04
Concrete Pad and Building	$54 227	$96.40
Total Cost	**$84 792**	**$117.28**

Source: Paul, J. (2000). Developing Cost-Effective In-Vessel Composting Technology for Animal Waste Composting. Abbotsford, Canada: Transform Compost Systems Ltd.

1. Based on 550 head.

The cost of composting using this technology is or $13.44 per tonne of raw manure, or $117.28 per head.

6.4 Summary

A review of the proposed structure of the *Clean Water Act* suggests that there is considerable opportunity for biosecurity strategies to be integrated into this legislation. Operational measures to prevent pathogenic loading, such as manure treatment prior to storage and handling, could be used as a means of mitigating drinking water risks in vulnerable areas. These measures may be best employed as conditions specified within risk management plans. Alternatively, manure treatment technologies may be incorporated as part of existing farm-level biosecurity programs and may eliminate the need for many operations to obtain permits under the *Clean Water Act*.

For activities that are required to develop risk management plans, cost effectiveness should be a primary consideration. A review of capital and annual operating expenditures revealed that there are significant costs associated with manure treatment technologies. These costs must be justified by the level of source water protection provided. As such, there may be scenarios that warrant the relocation of water intakes or wells that could result in less expenditure compared to regulating pathogen sources through the use of risk management plans. When activities do require site-specific management, biosecurity strategies should be considered a viable means of protecting the quality of drinking water sources. Given that pathogen abatement is both pathogen and site-specific, a standardized approach to preventing pathogenic contamination may not adequately protect sources of drinking water. Management regimes that focus on measurable targets, such as pathogen reductions, are the most effective in protecting the quality of sources of drinking water, although a cost-benefit analysis is required to fully ascertain the value of this approach.

The selection of manure treatment technologies is likely to be a critical step in the development of risk management plans. The process of selecting manure treatment technologies is complicated, however, by a number of additional factors including energy requirements, land availability, climate, and operational expertise. The significance of these factors illustrates the importance of conducting controlled studies in areas where land use activities contribute to the contamination of source water. Funding for these studies and for the implementation of risk management plans will be critical to the success of the *Clean Water Act*. The availability of scientific evidence to support the efficacy of manure treatment technologies at the commercial-scale is limited. This lack of evidence is likely to be a significant obstacle in the development of risk management plans for agricultural operations and will no doubt impede the overall progress of the *Clean Water Act*.

CHAPTER SEVEN: CONCLUSION

7.0 Conclusion

Presently, the scope of farm-level biosecurity is narrowly defined to address threats associated with outbreaks of disease in livestock. The concept of implementing proactive measures to prevent such threats is a relatively new concept in agricultural practice and only recently, as outbreaks of disease occur, have programs been fully developed to protect animal health. Although a number of industry organizations have developed biosecurity protocols, governing bodies largely rely on general guidance and not regulated practice. As these programs strengthen and the potential for other ecological impacts are recognized, the scope of biosecurity has expanded. Despite this broadening scope, operational biosecurity has yet to be recognized as an instrument in protecting source water from pathogenic contamination, although findings from this study suggest that the concept of biosecurity has been indirectly applied in many jurisdictions through the use of conceptual and structural restrictions in livestock operations.

A review of the implementation framework for the proposed *Clean Water Act* suggests that this legislation has the potential to be an effective instrument in protecting vulnerable sources of drinking water. Watersheds in south western Ontario are particularly susceptible to non-point sources of pollution due to the concentration of animal husbandry practices in this part of the province. The success achieved through the conventional application of farm-level biosecurity suggests that expanding its scope to include source water will effectively protect against pathogenic contamination of vulnerable drinking water supplies. The general strategies used in existing biosecurity programs should be used a model for the protection of drinking water supplies. Such strategies can be easily integrated with the proposed *Clean Water Act* by including them as mitigative measures within risk management plans to address site-specific risks.

The potential application of a farm-level biosecurity program to address non-point sources of pollution in sources of drinking water is largely dependent on the availability of operational measures that are capable of effectively treating manure prior to storage and land application. This investigation demonstrates that the level of pathogenic reduction achieved by manure treatment technologies is considerably high, although the data is limited due to a lack of studies conducted at the commercial-scale. Furthermore, the certainty of pathogenic reduction is limited given that the efficacy of manure treatment technologies is not well know in its application to typical livestock operations in Ontario. In addition, most studies conducted at the commercial-scale have focused on the removal of bacterial pathogens, rather than addressing highly resistant protozoan pathogens. This investigation also reveals that most treatment studies concentrate on pathogens that are prevalent, rather than those that are persistent. Since manure-related human epidemics have been attributed to those pathogens that are capable of survival for prolonged periods of time, rather than those that are the most prevalent, studies must take a greater initiative to address protozoan pathogens.

Although the anticipated costs of implementing watershed-based protection plans will be great, considerable human and financial resources will no doubt be spared by reducing dependence on treatment and response systems. In its infancy, however, the mechanisms for conducting risk assessments, developing management plans, and allocating financial resources have not been fully disclosed. As such, it is difficult to ascertain the extent to which this Act will be successfully executed. While the tiered approach of the Act draws on the information collected from studies aimed at characterizing watersheds and vulnerable sources of drinking water, it fails to recognize the importance of timely implementation of measures to mitigate potentially negative impacts to these sources. The potential risks to drinking water sources in Ontario were previously identified through the initial planning process for the *Clean Water Act*. It is more advantageous to identify and assess measures to manage risks in concert with exercises to determine where they exist, thereby advancing the progression of source water protection. Given the number of factors to be considered in the selection of treatment technologies, these findings clearly demonstrate that it is imperative that the province recognize that there is a lack of economically viable and commercially tested technology and take immediate action to address the deficiencies of this legislation if the intended goals of the *Clean Water Act* are to be met.

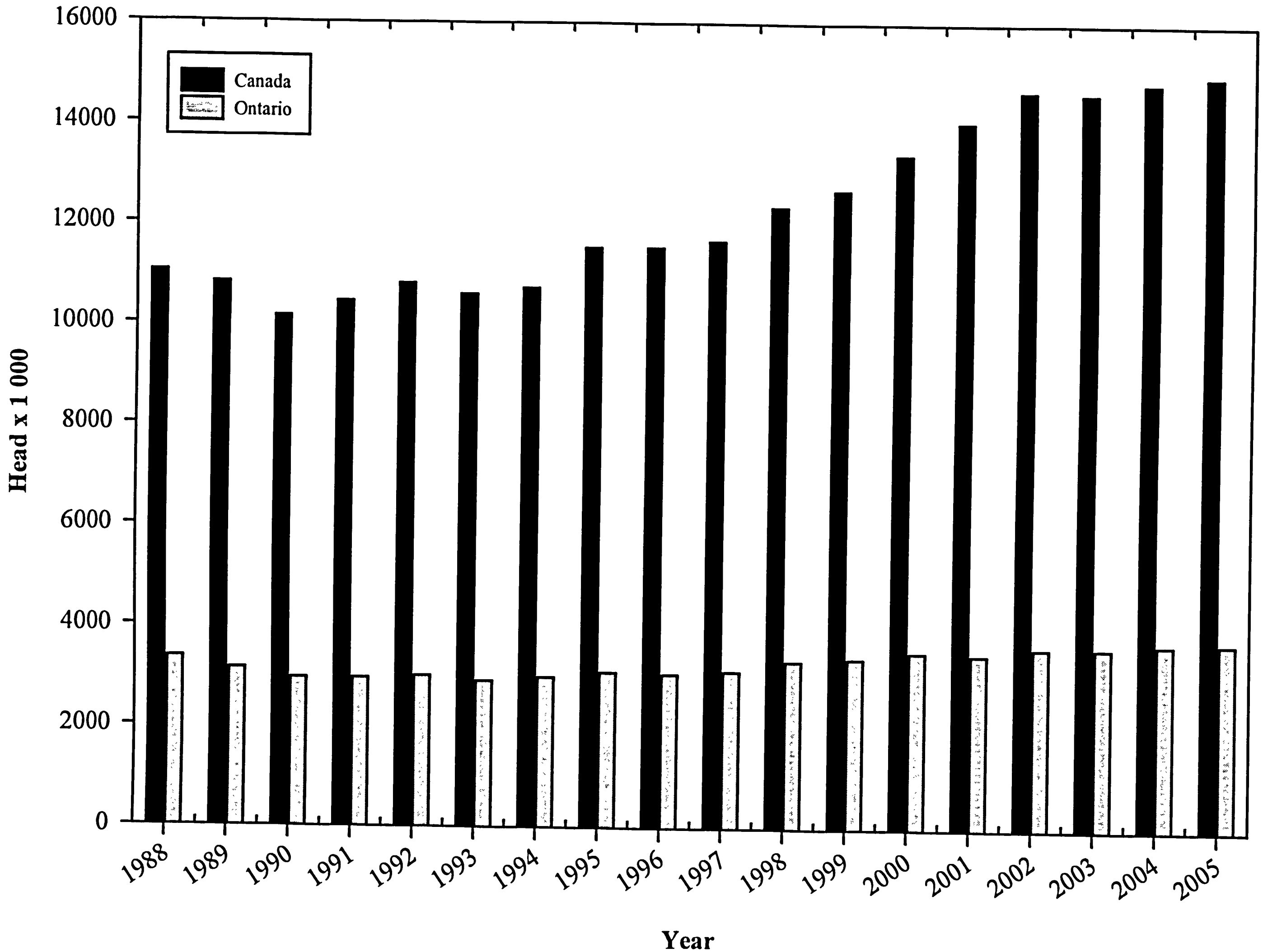
8.0 Appendices

Appendix 2.1: Number of Animals per Nutrient Unit in Ontario

Type of Animal (based on highest design capacity of a new barn of the farm unit at one time)	# Animals per NU
Dairy cow (large-frame, 1200-1400 lbs, milking or dry, such as Holsteins)	0.7
Dairy heifers (large-frame, 400-1200 lbs such as Holsteins)	2.0
Dairy calves (large-frame, 100-400 lbs, such as Holsteins)	6.0
* Dairy cow (large-frame, 1200-1400 lbs, milking or dry (Holsteins); includes calves/heifers)	*0.55
Dairy cow (medium-frame, 1000-1200 lbs, milking or dry, such as Guernseys)	0.85
Dairy heifers (medium-frame, 325-1000 lbs, such as Guernseys)	2.4
Dairy calves (medium-frame, 85-325 lbs, such as Guernseys)	7.0
* Dairy cow (medium-frame, 1000-1200 lbs, milking or dry (Guernseys); includes calves/heifers)	*0.66
Dairy cow (small-frame, 800-1000 lbs, milking or dry, such as Jerseys)	1.0
Dairy heifers (small-frame, 275-800 lbs, such as Jerseys)	2.9
Dairy calves (small-frame, 65-275 lbs, such as Jerseys)	8.5
*Dairy cow (small-frame, 800-1000 lbs, milking or dry (such as Jerseys); includes calves/heifers	*0.77
Beef cows (includes unweaned calf and replacements)	1.0
Beef shortkeepers (900-1300 lbs)	2.0
Beef backgrounders (575-900 lbs)	3.0
Beef feeders (575-1250 lbs)	3.0
SEW (Segregated Early Weaning) Sows (lactating-aged sows, includes weaners to 15 lbs)	3.33
SEW Weaners (15-60 lbs)	20.0
Sow farrow-wean (lactating-aged sows, includes weaners to 60 lbs)	2.5
Finishing pigs (60-230 lbs)	6.0
Horses, large-framed (mature at>1500 lbs; inc unweaned foal)	0.7
Horses, medium-framed (mature at 500 – 1500 lbs; inc unweaned foal)	1.0
Horses, small-framed (mature at < 500 lbs; includes unweaned foal)	2.0
Laying hens (after 2.9 lbs pullet stage, until end of laying period at about 3.75 lbs)	150
Layer pullets (day-old pullets placed, raised to 2.9 lbs)	500
Chicken broilers, floor growing area (total square feet, regardless of quota cycle, or finishing weight)	267 sq.ft
Turkey broiler/hen/tom growing space (total square feet, regardless of finishing weight)	267 sq.ft
Chicken broiler breeder growers (females and males transferred out to layer barn)	300
Chicken broiler breeder layers (females and males transferred in from grower barn)	100
Sheep, breeding-aged ewes (sheep raised for meat production; includes lambs, replacements and rams)	8.0
Feeder lambs, 70 to 125 lbs	20
Sheep, milking-aged ewes (sheep raised for milk production; includes lambs, replacements and rams)	6.0
Goats, milking-aged goats (goats raised for milk production; includes kids, replacements and bucks)	8.0
Milk-fed, or grain-fed veal calves	6.0

Adapted from: Ontario Ministry of Agriculture, Food, and Rural Affairs. (2005a). *Nutrient Management Protocol*; Section 3.

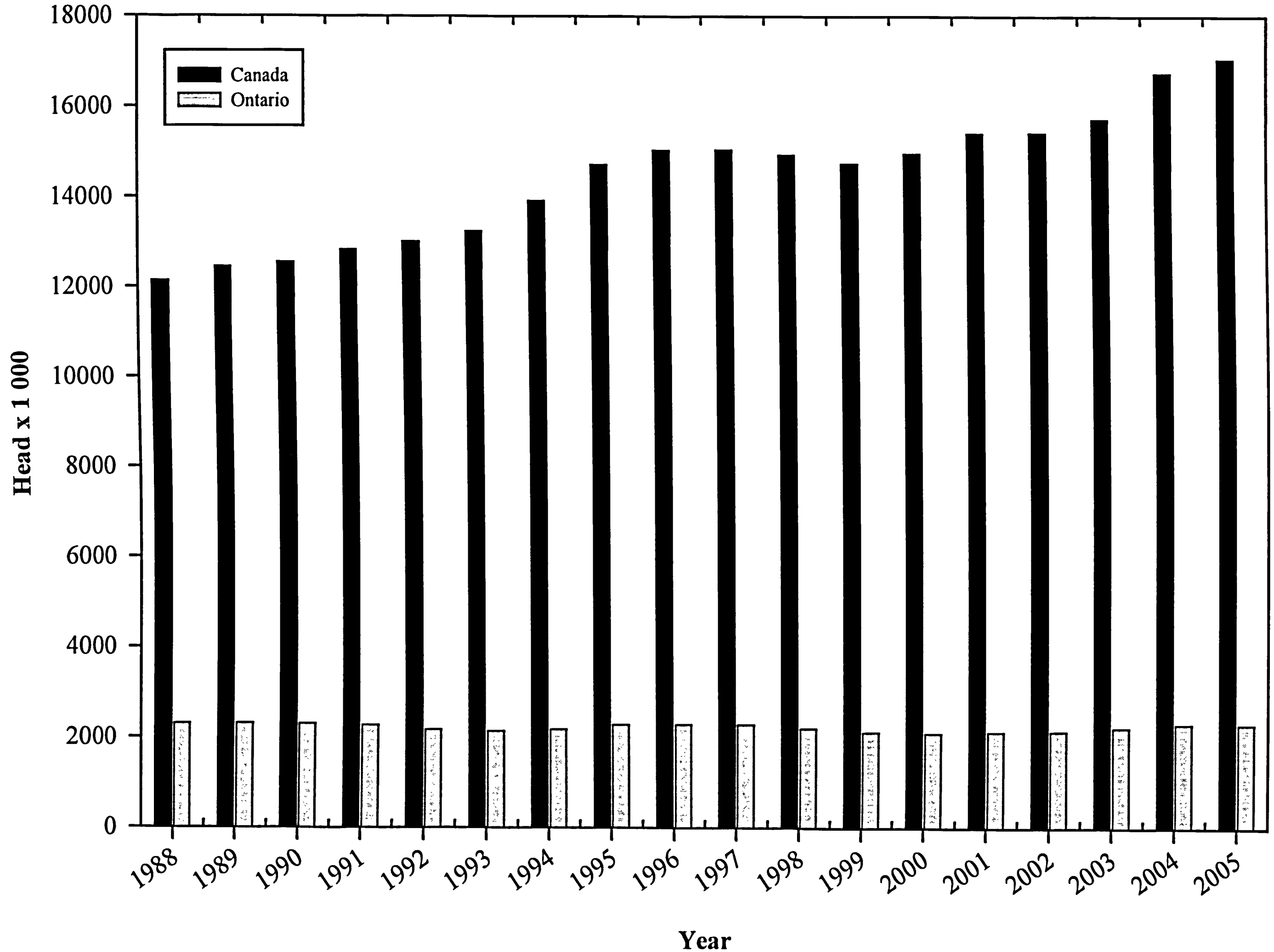
Appendix 2.2: Annual Pig Inventories at End of 2nd Quarter (1988-2005)[1]



Generated from: Statistics Canada - CANSIM Database. (2006e). *Table 003-0004 Livestock surveys, pigs, at end of quarter, quarterly*. Ottawa, Canada: Author.

1. Pig inventories include: breeding stock (boars, 6 months or over, sows and gilts, 6 months or over) and all other pigs (under 20 kilograms, 20-60 kilograms, and over 60 grams).

Appendix 2.3: Annual Cattle Inventories at July 1 (1988-2005) [1]



Generated from: Statistics Canada - CANSIM Database. (2006f). *Table 003-0032: Number of cattle on farms, by class, annual (Head)*. Ottawa, Canada: Author.

1. Cattle inventories include: bulls, milk cows, beef cows, dairy heifers, beef heifers (breeding and market), steers, calves.

Appendix 2.4a: Municipalities Affected by Proposed Alterations to Source Protection Areas' Boundaries[1]

Source Protection Regions	Municipalities Drawn into Source Protection Area	
	Upper Tier	**Lower Tier**
Grey Sauble	County of Bruce	• Municipality of Northern Bruce Peninsula
	County of Bruce*	• Town of The South Bruce Peninsula*
Lake Simcoe	County of Simcoe*	• Township of Severn • Township of Ramara*
	City of Kawartha Lakes*	• City of Kawartha Lakes*
	District Municipality of Muskoka	• Town of Bracebridge • Town of Gravenhurst • Township of Georgian Bay • Township of Muskoka Lakes • Township of Lake of Bays
	County of Haliburton	• Township of Algonquin Highlands • Township of Minden Hills • Township of Dysart et al
Nottawasaga	County of Simcoe*	• Township of Severn • Township of Tay • Township of Tiny • Town of Penetanguishene • Town of Midland • City of Orillia*
Lakehead	Thunder Bay	• Thunder Bay*
North Bay - Mattawa	District of Parry Sound	• Municipality of Powassan • Township of Joly • Township of Machar • Township of Nipissing • Township of Strong • Village of South River
	Nippising	• Nippising
Raisin Region	United Counties of Prescott and Russell*	• Township of Champlain • Township of East Hawkesbury
	United Counties of Stormont, Dundas and Glengarry*	• South Dundas*

Source: Ontario Ministry of the Environment. (2005f). *Notice of Proposal of Regulation. EBR Registry Number RA05E0022.* Toronto, Canada: Author; Table 1.

1. Only significant boundary changes are provided in this table.

* Area of the municipality within the source protection area is being enlarged or reduced due to proposed boundary changes. All other municipalities were not previously within a Conservation Authority area.

Appendix 2.4b: Municipalities Affected by Proposed Alterations to Source Protection Areas' Boundaries[1]

Source Protection Regions	**Municipalities Drawn into Source Protection Area**	
	Upper Tier	**Lower Tier**
South Nation	United Counties of Prescott and Russell*	• Township of Champlain • Town of Hawkesbury • Township of Alfred and Plantagenet* • City of Clarence-Rockland • Municipality of the Nation*
	United Counties of Leeds and Grenville*	• Separated Town of Prescott • Township of Augusta* • Township of Edwardsburg Cardinal*
Sudbury (Nickel District CA	Region of Sudbury*	• Municipality of Killamey* • Municipality of Markstay-Warren* • Town of Espanola*
Kawartha	County of Peterborough*	• Township of Galway-Cavendish and Harvey
	County of Haliburton*	• Township of Minden Hills • Municipality of Highlands East • Township of Dysart et al • Township of Algonquin Highlands
Otonabee	County of Haliburton*	• Township of Dysart et al • Municipality of Highlands East
	County of Peterborough*	• Township of Galway-Cavendish and Harvey* • Township of North Kawartha*

Source: Ontario Ministry of the Environment. (2005f). *Notice of Proposal of Regulation. EBR Registry Number RA05E0022.* Toronto, Canada: Author; Table 1.

2. Only significant boundary changes are provided in this table.

* Area of the municipality within the source protection area is being enlarged or reduced due to proposed boundary changes. All other municipalities were not previously within a Conservation Authority area.

Appendix 2.5: Proposed Source Protection Regions

Source Protection Regions	Source Protection Areas
Ausable Bayfield Maitland	• Ausable Bayfield • Maitland
CTC	• Toronto Region • Credit Valley • Central Lake Ontario
Saugeen Grey Sauble	• Saugeen Valley • Grey Sauble
Lake Erie	• Grand River • Long Point • Catfish Creek • Kettle Creek
Halton – Hamilton	• Hamilton • Halton
Lake Simcoe, Nottawasaga, Black River and Severn Sound Environmental Association	• Lake Simcoe • Nottawasaga
Quinte	• Prince Edward Region • Napanee Region • Moira Region
Raisin Region South Nation	• Raisin River • South Nation
Rideau-Mississippi Valley	• Rideau • Mississippi Valley
Thames – Sydenham and Region	• Upper Thames River • St. Clair • Lower Thames Valley
Trent Conservation Coalition	• Kawartha • Ottonabee • Ganaraska • Lower Trent • Crowe Valley

Source: Ontario Ministry of the Environment. (2005f). *Notice of Proposal of Regulation. EBR Registry Number RA05E0022*. Toronto, Canada: Author; Table 2.

Appendix 2.6: Proposed Implementation of the *Clean Water Act*

Step 1	Step 2	Step 3	Step 4
Terms of Reference	**Risk Assessment Report**	**Source Protection Plan**	**Regulation of Drinking Water Threats**
• Identify roles and responsibilities for planning process • Outline public consultation process	• Identify watersheds in Source Protection Areas • Identify vulnerable areas within watersheds • Assess drinking water threats and determine significance	• Designate activities that pose a threat to vulnerable areas • Develop policies to ensure existing activities identified in the risk assessment as "significant" ceases to be a threat • Develop policies for future activities	Develop prohibitions against: (a) engaging in an activity designated by the Source Protection Plan within a wellhead protection area of surface water intake protection zone, (b) engaging in existing/future activities unless the activity occurs in accordance with: (i) a permit (ii) risk assessment that concludes that the activity is not a significant drinking water threat, or (c) construction requiring approval under a prescribed provision of the *Planning Act* in connection with a land use designated in the Source Protection Plan without having the proposal reviewed by the permit official

Generated from: Ontario. Legislative Assembly. (2006). *Bill 43: An Act to protect existing and future sources of drinking water and to make complementary and other amendments to other Acts* (2nd Session, 38th Legislature). Toronto, Canada: Author.

Appendix 4.1: Manure Related Human Epidemics

Location	Year	Pathogen	Impact	Suspected Source	Reference
Walkerton, Ontario, Canada	2000	*E. coli* O157: H7 and *Campylobacter* spp.	2300 cases, 6 deaths	Run-off from farm fields entering town's water supply	Valcour *et al.*, 2002
Washington County, NY	1999	*E. coli* O157: H7 and *Campylobacter* spp.	2 deaths, 116 cases	Run-off at fairgrounds	Public Health Dispatch, 1999
Carrollton, GA	1989	*Cryptosporidium parvum*	13 000 cases	Manure run-off	Solo-Gabriele and Nemeister, 1996
Swindon and Oxfordshire, UK	1989	*Cryptosporidium parvum*	516 cases	Run-off from farm fields	Richardson *et al.*, 1991
Bradford, UK	1994	*Cryptosporidium parvum*	125 cases	Storm run-off from farm fields	Atherton *et al.*, 1995
Milwaukee, WI	1993	*Cryptosporidium parvum*	100 000 cases, 87 deaths	Animal manure and/or human excrement	MacKenzie *et al.*, 1994
Maine and Others	1993	*E. coli* O157: H7	Several illnesses	Animal manure spread in apple orchard	Cieslak *et al.*, 1993
Cabool, MO	1990	*E. coli* O157: H7	243 cases, 4 deaths	Water line breaks in farm community	Geldreich *et al.*, 1992
Sakai City, Japan	1995	*E. coli* O157: H7	12 680 cases, 425 hospitalized, 3 deaths	Animal manure used in fields growing alfalfa sprouts	Fukushima *et al.*, 1999

Source: Smith, J.E. Jr,. and Perdek, J.M. (2004). Assessment and Management of Watershed Microbial Contaminants. *Critical Reviews in Environmental Science and Technology,* 34(2): 109-140; p. 118.

Appendix 4.2: Current List of Nationally Notifiable Diseases

Disease	First Positive Case (Year)
Acute Flaccid Paralysis	2000 -
AIDS	1986 -
Amoebiasis	1927 - 1999
Botulism	1933, 1940 -
Brucellosis	1928 -
Campylobacteriosis	1986 -
Chancroid	1979 - 1999
Chickenpox	1924 to 1959, 1986 -
Chlamydia, Genital	1990 -
Cholera	1974 -
Creutzfeld-Jakob Disease	2000 -
Cryptosporidiosis	2000 -
Cyclosporiasis	2000 -
Diphtheria	1924 -
Giardiasis	1983 -
Gonorrhea	1924 -
Gonococcal Ophthalmia Neonatorum	1979 - 1999
Group B Streptococcal Disease of the Newborn	2000 -
Hantavirus Pulmonary Syndrome	2000 -
Hepatitis A	1927 to 1958, 1969 -
Hepatitis B	1969 -
Hepatitis C	1991 -
Hepatitis Non-A, Non-B	1983 - 1999
Human Immonodeficiency Virus	2000 -
Influenza,Laboratory-Confirmed	2000 -
Invasive *Haemophilus influenzae* type b Disease	1979 -
Invasive Group A Streptococcal Disease	2000 -
Invasive Meningococcal Disease	1924 -
Invasive Pneumococcal Disease	2000 -
Legionellosis	1986 -
Leprosy	1925 -
Listeriosis (all types)	1990 - 1999
Malaria	1929 to 1978, 1983 -
Measles	1924 -
Meningitis, Pneumococcal	1979 - 1999
Meningitis, Other Bacterial	1979 - 1999
Meningitis, Viral	1952 - 1999
Mumps	1924 to 1959, 1986 -
Paratyphoid	1924 to 1952, 1969 - 1999
Pertussis	1924 -
Plague	No reports of this disease have been received
Poliomyelitis	1924 -
Rabies	1927 -
Rubella	1924 -
Rubella, Congenital	1979 -
Salmonellosis	1958 -
Shigellosis	1924 -
Syphilis, Congenital	1992 -
Syphilis, Early Latent	1992 -
Syphilis, Early Symptomatic	1979 -
Syphilis, Other	1924 -
Tetanus	1957 -
Tuberculosis	1924 -
Trichinosis	1929 - 1999
Typhoid	1924 to 1952, 1969 -
Verotoxigenic *E. coli*	1990 -
Yellow Fever	No reports of this disease have been received

Source: Public Health Agency of Canada. (2003a). National Notifiable Diseases for 2000; Table 1.

Appendix 4.3: Survival Characteristics of Bacterial Waterborne Pathogens

Pathogen	Agricultural Sources[1]	Survival Characteristics[2]			ID 50
		Medium	Temperature	Time	
Escherichia coli 0157:H7	Cattle are the primary reservoir though humans can also be a carrier	Water	Frozen Cold (5°C) Warm (30°C)	> 300 days > 300 days 84 days	Low[3] (100)
		Soil	Frozen Cold (5°C) Warm (30°C)	> 300 days 100 days 2 days	
		Cattle Feces	Frozen Cold (5°C) Warm (30°C)	> 100 days > 100 days 10 days	
		Slurry	-	10 – 100 days	
		Compost	-	7 days	
		Dry Surfaces	-	1 day	
Salmonella typhimurium and *Salmonella enteritis*	Food or water contaminated with animal or human feces	Water	Frozen Cold (5°C) Warm (30°C)	> 6 months > 6 months > 6 months	High[1] (10^6 to 10^7)
		Soil	Frozen Cold (5°C) Warm (30°C)	> 12 weeks 12 – 28 weeks 4 weeks	
		Cattle Feces	Frozen Cold (5°C) Warm (30°C)	> 12 weeks 12 – 28 weeks 4 weeks	
		Slurry	-	13 – 75 days	
		Compost	-	7 – 14 days	
		Dry Surfaces	-	1 – 4 days	
Campylobacter	Food or water contaminated with animal or human feces	Water	Frozen Cold (5°C) Warm (30°C)	2-8 weeks 12 days 4 days	High[4] 1000
		Soil	Frozen Cold (5°C) Warm (30°C)	2-8 weeks 2 weeks 1 week	
		Cattle Feces	Frozen Cold (5°C) Warm (30°C)	2-8 weeks 1-3 weeks 1 week	
		Slurry	-	> 112 days	
		Compost	-	7 days	
		Dry Surfaces	-	1 day	

1. Source: Kelly, A. (2005). *The Characterization of Significant Direct Threats to Source Watersheds: A Risk-Based Approach* Masters Thesis. Toronto, Canada: Ryerson University; p. 140
2. Source: Olson, M.E. (2001, June). *Human and Animal Pathogens in Manure.* Presented at Livestock Options for the Future, Winnipeg, Manitoba; p. 9.
3. Source: World Health Organization. (2004). *Guidelines for Drinking Water Quality Volume 1 Recommendations* (3rd ed.). Geneva, Switzerland: Author; p. 230.
4. Source: Ibid; p. 228.

Appendix 4.4: Survival Characteristics of Protozoan Waterborne Pathogens

Pathogen	Agricultural Sources[1]	Survival Characteristics[2]			ID_{50}
		Medium	Temperature	Time	
Giardia lamblia	Surface water contaminated with human or animal feces.	Water	Frozen Cold (5°C) Warm (30°C)	< 1 day 11 weeks 2 weeks	Low [3] 50 - 100 cysts
		Soil	Frozen Cold (5°C) Warm (30°C)	< 1 day 7 weeks 2 weeks	
		Cattle Feces	Frozen Cold (5°C) Warm (30°C)	< 1 day 1 week 1 week	
		Slurry	-	1 year	
		Compost	-	2 weeks	
		Dry Surfaces	-	1 day	
Cryptosporidium parvum	Water contaminated with mammalian (especially human feces. Significant sources are wastewater discharges and agricultural run-off	Water	Frozen Cold (5°C) Warm (30°C)	> 1 year > 1 year 10 weeks	High [3] 30 oocysts
		Soil	Frozen Cold (5°C) Warm (30°C)	> 1 year 8 weeks 4 weeks	
		Cattle Feces	Frozen Cold (5°C) Warm (30°C)	> 1 year 8 weeks 4 weeks	
		Slurry	-	> 1 year	
		Compost	-	4 weeks	
		Dry Surfaces	-	1 day	

1. Source: Kelly, A. (2005). *The Characterization of Significant Direct Threats to Source Watersheds: A Risk-Based Approach* Masters Thesis. Toronto, Canada: Ryerson University; p. 141.
2. Source: Olson, M.E. (2001, June). *Human and Animal Pathogens in Manure*. Presented at Livestock Options for the Future, Winnipeg, Manitoba; p. 9.
3. Source: Finch, G.R., and Belosevic, M. (2002). Controlling *Giardia* spp. and *Cryptosporidium* spp. in drinking water by microbial reduction processes. *Journal of Environmental Engineering and Science,* 1: 17-31; p. 18-19.

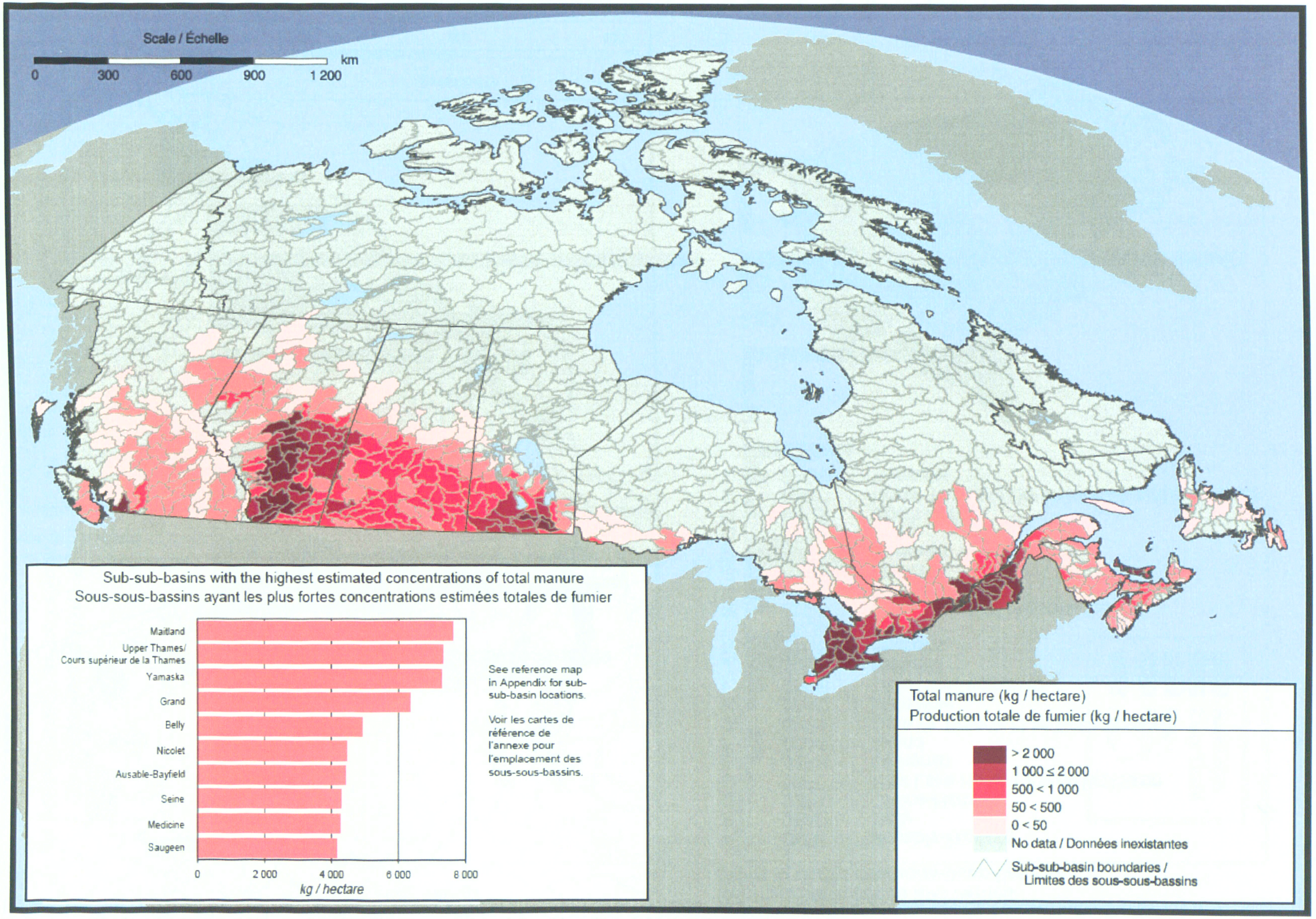
Appendix 4.5: Manure Application during Winter and Other Times When Soil is Snow Covered or Frozen[1]

Criterion	Solid			Liquid	
Time	Between December 1 of one year and ending on March 31 of the following year when the soil of the land is **not snow-covered or frozen.**	Any time when the soil of the land is snow-covered or frozen		Between December 1 of one year and ending on March 31 of the following year when the soil of the land is **not snow-covered or frozen.**	Any time when the soil of the land is snow-covered or frozen
Application	i) Injection; or ii) Spreading and incorporation into the soil within the same day;	Spreading and incorporation into the soil within six hours	Surface application	iii) Injection; iv) Spreading and incorporation into the soil within the same day; or v) Surface application, if the land is covered by a living crop or crop residue that covers at least 30 percent of the land surface	i) Injection; or ii) Spreading and incorporation into the soil within six hours
Setback from the top of the bank of surface water	N/A	N/A	100 m or more	20 m or more.	20 m or more
Slope	The materials must not be applied within 100 metres from the top of the bank of surface water, if the maximum sustained slope of the land is greater than 6 per cent.	The materials must not be applied within 100 metres from the top of the bank of surface water, if the maximum sustained slope of the land is greater than 6 %	The maximum slope of the area of application must be less than 3 % and the he maximum depth of snow in the area of application must not exceed 15 cm.	The materials must not be applied within 100 metres from the top of the bank of surface water, if the maximum sustained slope of the land is greater than 3 per cent	The materials must not be applied within 100 metres from the top of the bank of surface water, if the maximum sustained slope of the land is greater than 3 per cent

Generated from: Ontario Regulation 267/03. General Regulation made under the *Nutrient Management Act*. S.O. 2002. Chapter 4.

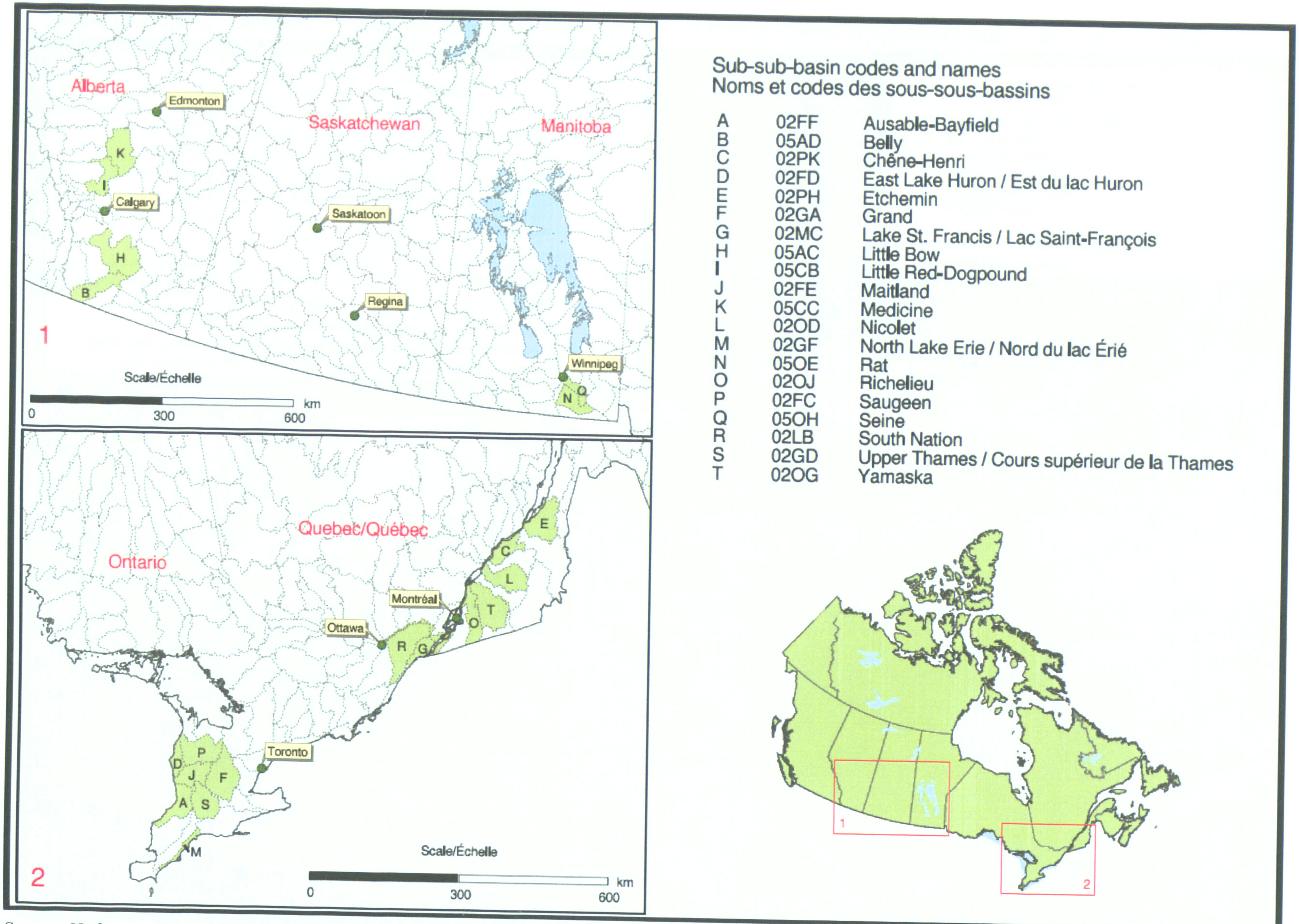
1. For lands that are not subject to flooding or that drain into surface water.

Appendix 5.1: Estimated Total Livestock Manure Production by Sub-sub-basin, 1996



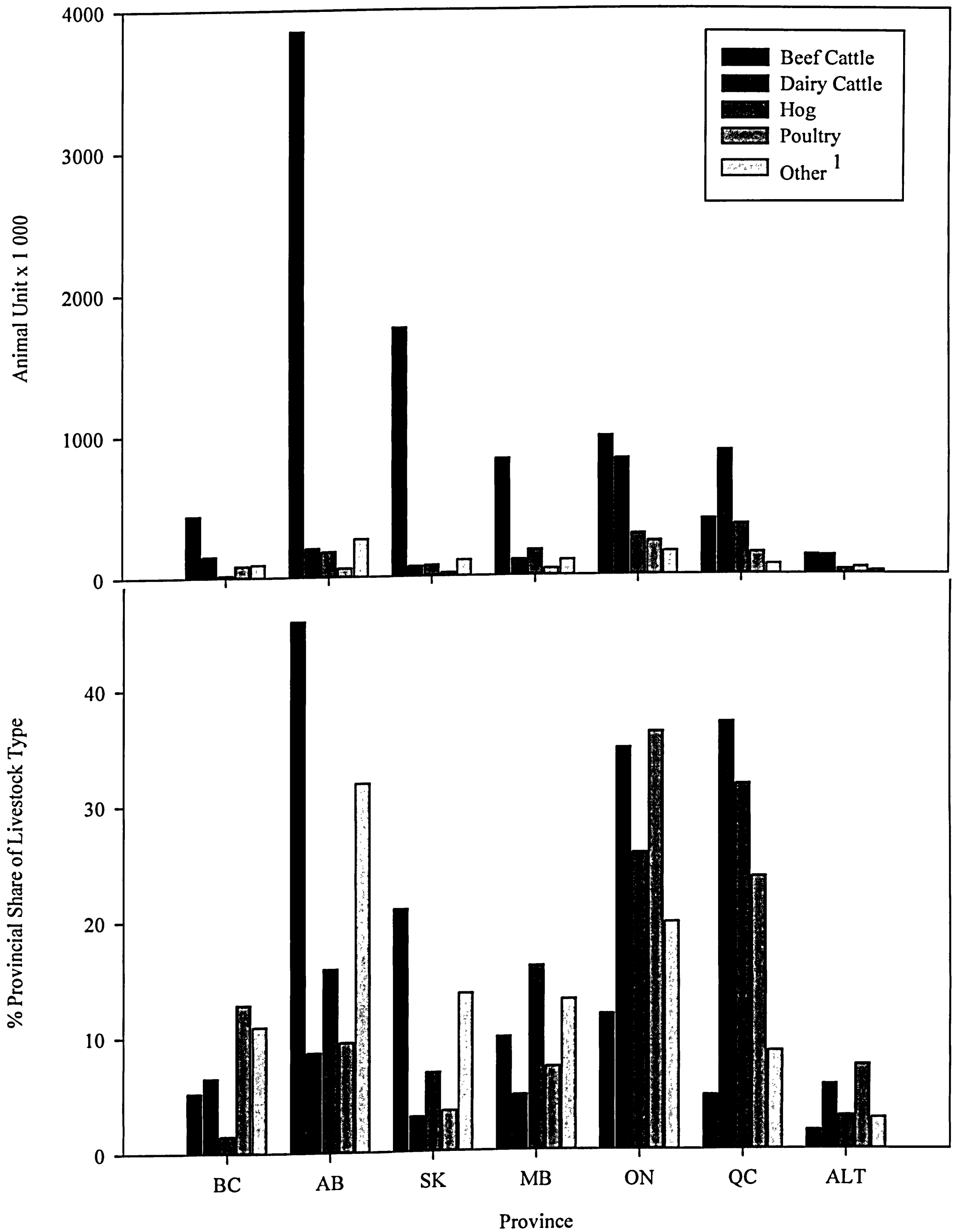
Source: Hofmann, N., and Kemp, L. (2001). *Geographical Profile of Manure Production in Canada*. (Catalog No.16F0025XIB). Ottawa, Canada: Statistics Canada; p. 4

Appendix 5.2: Reference Map for Sub-sub Basins in Canada



Source: Hofmann, N., and Kemp, L. (2001). *Geographical Profile of Manure Production in Canada.* (Catalog No.16F0025XIB). Ottawa, Canada: Statistics Canada; p. 15

Appendix 5.3: Number and Proportion of Livestock in High-Density Areas by Type and Province



Generated from: Source: Beaulieu, M.S., Bédard, F., and Lanciault, P. (2001). *Distribution and Concentration of Canadian Livestock* (Working Paper No. 47). Statistics Canada: Ottawa, Canada; pg. 15

1. Other livestock include sheep, horses, and exotic animals.

Appendix 6.1.1: Standardized Quantities and Costs for the Super Soil Technology - Manure Evacuation and Lift Station

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Manure Evacuation and Lift Station	Manure Evacuation	$5 168.88	$770.32
	Lift Station		
	Concrete Lift Station	$2 413.66	$359.71
	Switches and Brackets	$143.55	$21.39
	Pumps	$3 935.84	$1 418.27
	Piping	$165.30	$24.64
	Lift Station Accessories	$8 755.58	$1 304.84
	Electrical Panel	$1 208.96	$180.17
	Labour (Electrical)	$3 495.09	$520.87
	Electrical Material	$3 265.41	$486.65
	Contractor and Engineering Services and Overhead	$12 306.02	$1 833.96
	Total Construction Costs	**$40 858.29**	**$6 920.80**
	Electrical Power Costs		$268.01
	Maintenance Costs		$619.22
	Property Taxes		$145.05
	Total Operating Costs		**$1 032.28**
	Total Annualized Cost of Manure Evacuation and Lift Station		**$7 953.08**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 36.

Appendix 6.1.2: Standardized Quantities and Costs for the Super Soil Technology - Strainer

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Strainer	Pit	$158.87	$23.67
	Strainer	$283.69	$42.28
	Fittings/Pipe	$158.92	$23.68
	Labour	$567.39	$84.55
	Contractor and Engineering Services and Overhead	$503.78	$75.08
	Total Construction Costs	**$1 672.65**	**$249.27**
	Maintenance Costs		$23.38
	Property Taxes		$5.93
	Total Operating Costs		**$29.31**
	Total Annualized Cost of Manure of Strainer		**$278.59**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 36.

Appendix 6.1.3: Standardized Quantities and Costs for the Super Soil Technology - Homogenization Tank

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Homogenization Tank	Tank	$33 001.15	$4 918.15
	Mixer and Controls	$6 445.49	$960.57
	Screen	$11 347.70	$1 691.14
	Materials and Equipment	$13 741.72	$2 047.92
	Labour – General	$1 475.55	$219.90
	Labour – Mechanical	$1 985.14	$295.85
	Labour – Electrical	$7 020.61	$1 046.28
	Contractor and Engineering Services and Overhead	$18 139.63	$2 698.78
	Total Construction Costs	**$93 126.36**	**$13 878.58**
	Electric Power Costs		$2 535.26
	Maintenance Costs		$1 290.72
	Property Taxes		$330.60
	Total Operating Costs		**$4 156.58**
	Total Annualized Cost of Manure of Homogenization Tank		**$18 035.15**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 37.

Appendix 6.1.4: Standardized Quantities and Costs for the Super Soil Technology – Separation Building

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Separation Building	Materials – General	$9 954.41	$1 483.50
	Materials and Equipment	$5 993.96	$893.28
	Labour – General	$19 784.36	$2 948.45
	Steel Structure	$13 238.23	$1 972.89
	Steel Stair	$2 836.93	$422.78
	Labour – Mechanical	$1 200.59	$179.02
	Labour – Electrical	$3 689.42	$549.83
	Contractor and Engineering Services and Overhead	$24 437.09	$3 641.84
	Total Construction Costs	**$81 135.65**	**$12 091.60**
	Maintenance Costs		$640.48
	Property Taxes		$288.03
	Total Operating Costs		**$928.50**
	Total Annualized Cost of Manure of Separation Building		**$13 020.10**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 37.

Appendix 6.1.5: Standardized Quantities and Costs for the Super Soil Technology – Solids Separator

Phase	Component	Total Cost SCAN	Annualized Cost SCAN
Solids Separator	Storage	$11 347.70	$1 691.14
	Main Module	$147 520.10	$21 984.84
	Dehydration System	$23 262.79	$3 466.84
	Support Belt Filter	$2 156.06	$321.32
	Materials and Equipment	$9 350.11	$1 393.44
	Shipping	$8 663.27	$1 291.08
	Labour – Mechanical	$3 757.25	$559.94
	Labour – Electrical	$16 443.88	$2 450.63
	Contractor and Engineering Services and Overhead	$95 897.99	$14 291.63
	Total Construction Costs	**$318 399.15**	**$47 450.86**
	Electric Power Costs		$3 117.85
	Polymer Costs		$18 514.01
	Maintenance Costs		$9 114.45
	Property Taxes		$1 130.32
	Total Operating Costs		**$31 876.62**
	Total Annualized Cost of Manure of Solids Separator		**$79 327.48**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 38.

Appendix 6.1.6: Standardized Quantities and Costs for the Super Soil Technology – Observation Desk

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Observation Desk	Material – General	$991.98	$147.84
	Steel	$4 317.70	$643.46
	Labour	$6 734.86	$1 003.69
	Contractor and Engineering Services and Overhead	$5 191.20	$773.64
	Total Construction Costs	**$17 235.74**	**$2 567.98**
	Maintenance Costs		$106.19
	Property Taxes		$61.19
	Total Operating Costs		**$167.38**
	Total Annualized Cost of Manure of Observation Deck		**$2 736.01**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 38.

Appendix 6.1.7: Standardized Quantities and Costs for the Super Soil Technology – Denitrification Tank

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Denitrification Tank	Tank	$33 001.15	$4 918.15
	Mixer	$5 390.16	$803.29
	Mixer Controls	$794.34	$118.38
	Material and Equipment	$11 298.41	$1 683.79
	Labour	$2 411.93	$359.45
	Probes/Meters	-	-
	Contractor and Engineering Services and Overhead	$8 574.67	$1 277.88
	Total Construction Costs	**$61 470.66**	**$9 160.94**
	Electrical Power Costs		$1 319.35
	Maintenance Costs		$1 009.68
	Property Taxes		$218.22
	Total Operating Costs		**$2 547.26**
	Total Annualized Cost of Manure of Denitrification Tank		**$11 708.21**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 38.

Appendix 6.1.8: Standardized Quantities and Costs for the Super Soil Technology – Nitrification Tank

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Nitrification Tank	Tank	$25 172.51	$3 751.45
	Screen Housing	$6 651.19	$94.75
	Screen	$1 931.08	$287.79
	Diffusers	$2 246.13	$334.73
	Tank floor	$635.47	$94.71
	BIO-N Cubes/Engineering	$163 560.99	$24 375.42
	Material and Equipment	$13 028.93	$1 941.69
	Labour	$8 003.63	$1 192.78
	Probes/Meters		
	Contractor and Engineering Services and Overhead	$84 500.76	$12 593.11
	Total Construction Costs	**$305 730.71**	**$45 562.89**
	Electrical Power Costs		$5 996.62
	Maintenance Costs		$1 060.69
	Property Taxes		$1 085.34
	Total Operating Costs		**$8 142.66**
	Total Annualized Cost of Manure of Nitrification Tank		**$53 705.54**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 39.

Appendix 6.1.9: Standardized Quantities and Costs for the Super Soil Technology – Settling Tank

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Settling Tank	Tank	$41 411.79	$6 171.58
	Material and Equipment	$11 604.36	$1 729.39
	Labour	$4 073.12	$607.01
	Contractor and Engineering Services and Overhead	$6 757.00	$1 006.99
	Total Construction Costs	**$63 846.27**	**$9 514.98**
	Electrical Power Costs		$178.06
	Maintenance Costs		$1 060.32
	Property Taxes		$226.66
	Total Operating Costs		**$1 465.03**
	Total Annualized Cost of Manure of Settling Tank		**$10 980.01**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 39.

Appendix 6.1.10: Standardized Quantities and Costs for the Super Soil Technology – Clean Water Tank

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Clean Water Tank	Tank	$22 837.25	$3 403.42
	Material and Equipment	$5 275.76	$786.25
	Labour	$1 518.49	$226.30
	Contractor and Engineering Services and Overhead	$2 928.32	$436.41
	Total Construction Costs	**$32 559.82**	**$4 852.38**
	Maintenance Costs		$562.26
	Property Taxes		$115.59
	Total Operating Costs		**$677.84**
	Total Annualized Cost of Manure of Clean Water Tank		**$5 530.22**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 39.

Appendix 6.1.11: Standardized Quantities and Costs for the Super Soil Technology – Phosphorous Removal

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Phosphorous Removal	Settling Tank	$17 809.08	$2 654.08
	Draimad System	$13 071.42	$1 948.03
	Polymer Preparer	$6 734.86	$1 003.69
	Polymer Mixer	$640.01	$95.38
	Shipping	$1 359.02	$202.53
	Materials – General	$1 091.15	$162.61
	Materials – Mechanical	$4 255.39	$634.18
	Materials – Electrical	$33 793.55	$5 036.23
	Labour – General	$11 988.85	$1 786.70
	Labour – Mechanical	$3 971.70	$591.90
	Labour – Electrical	$5 756.69	$857.92
	Contractor and Engineering Services and Overhead	$43 303.31	$6 453.47
	Total Construction Costs	**$143 775.02**	**$21 426.72**
	Electrical Power Costs		$855.81
	Lime Slurry Costs		$2 698.26
	Polymer Costs		$373.26
	Phosphorus and Lime Cost Savings		$1 131.92
	Maintenance Costs		$1 547.91
	Property Taxes		$510.40
	Total Operating Costs		**$4 853.71**
	Total Annualized Cost of Manure of Phosphorous Removal		**$26,280.42**

Generated from: Task 1 Team. (2005).Technology report: Super Soils On-Farm. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 2 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 40.

Appendix 6.2.1: Predicted Standardized Costs for the Super Soil Composting Facility – Composting Building

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Composting Building	Site preparation and concrete slab	$30 892.98	$4 603.97
	Compost building	$57 385.32	$8 552.10
	Compost bins	$18 309.51	$2 728.66
	Electrical Costs	$17 973.62	$2 678.60
	Grass Seeding (for 50 foot buffer)	$228.72	$34.09
	Contractor and Engineering Services and Overhead	$53 685.98	$8 000.80
	Total Construction Costs	**$178 476.14**	**$26 598.20**
	Maintenance Cost		$2 491.23
	Property Taxes		$633.59
	Total Operating Costs		**$3 124.82**
	Total Annualized Cost of Manure of Composting Building		**$29 723.03**

Generated from: Task 1 Team. (2006).Technology report: Super Soils Composting. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 3 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 23.

Appendix 6.2.2: Predicted Standardized Costs for the Super Soil Composting Facility – Composting Equipment

Phase	Component	Total Cost $CAN	Annualized Cost $CAN
Composting Equipment	Agitated Bin Composter (7.5 HP)	$78 406.93	$30 424.52
	Front-end Loader (IH Tractor – 60 HP)	$4 539.08	$676.46
	Truck (1/5 Ton Pick-Up)	$23 830.17	$3 551.40
	Trailers	$7 489.48	$1 116.15
	Thermometers	$226.95	$33.83
	Contractor and Engineering Services and Overhead	$49 346.32	$7 354.06
	Total Construction Costs	**$163 838.94**	**$43 156.40**
	Maintenance Cost		$5 493.14
	Electrical Power		$3 384.29
	Tractor Operating Cost		$6 828.89
	Bulking Agent[1]		$1 806.54
	Property Taxes		$581.63
	Total Operating Costs		**$18 094.49**
	Total Annualized Cost of Manure of Composting Building		**$61 250.89**

Generated from: Task 1 Team. (2006).Technology report: Super Soils Composting. In C.M. Williams (Agreements Designee), *Development of Environmentally Superior Technologies: Phase 3 Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers* (Appendix B11). Raleigh, NC: North Carolina State University Animal and Poultry Waste Management Center; p. 24.

1. Costs of the composting system were modelled on the use of cotton gin trash as the bulking agent.

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