The Walkerton Inquiry

Commissioned Paper 6

The Management of Manure in Ontario with Respect to Water Quality

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Toronto

2002

Published by Ontario Ministry of the Attorney General

This paper and other Walkerton Inquiry Commissioned Papers are available on the Walkerton Inquiry CD-ROM and at <www.walkertoninquiry.com> with the complete final report.

General editor, Commissioned Papers: Sheila Protti
Editor: Rosemary Tanner, with Lynda Lyons
Proofreader: Lynda Lyons
Design: Madeline Koch, Wordcraft Services; Brian Grebow, BG Communications

Abstract

This paper provides an account of current manure management in Ontario with reference to impacts on the quality of water sources used for drinking. Section 1 highlights those manure components that have the potential to result in the contamination of drinking water. Section 2 covers the regulatory framework governing manure management and the biophysical processes that govern the potential risks to water resources. We compare current regulations in Ontario with those in other parts of Canada, North America, and Europe.

In section 3, we identify the current understanding of how the quality of water resources can be impacted by manure at different stages of the management system. And section 4 provides an assessment of the potential changes in manure production in Ontario over the next decade, both in terms of amount and its distribution. In documenting the information that underpins management options, we have taken account of the literature from other areas of North America and Europe.

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1 Introduction

Manure management is a multi-faceted issue. Manure handling practices, water quality, and livestock concentrations vary across regions because of different biophysical, economic, and demographic factors. Biophysical factors influence the nature and properties of manure and its components as they impact on water quality. Social and economic factors influence the benefits and costs that flow from animal agriculture and water quality impairment. Regulatory policy must address both biophysical and social economic aspects as it attempts to minimize the impact of animal agriculture on rural residents and the environment. The biophysical, social, and economic factors combine to determine where animal agriculture can flourish, and hence where and how much manure will be produced.

Prepared for the Walkerton Inquiry, this document is an issue paper describing basic information on manure production and handling as it affects water quality in selected jurisdictions. The information is presented within an analytical framework that encompasses the social and economic considerations which govern regulatory policy.

Objectives

The objectives of this document are:

- To describe regulatory policy for manure management in Ontario relative to other jurisdictions, and to explain why different policy instruments exist to achieve similar goals.

- To describe what is known about the potential for contamination of water resources from manure production and handling, and to consider effects of various livestock feeding, nutrient transport, and cropping practices.

- To describe the distribution of animal agriculture in Ontario and associated manure production with an emphasis on trends over the next ten years.

Within the second objective, we indicate where information is still needed to protect water resources while allowing efficient agricultural production to continue on Ontario farms.

This paper has been prepared for discussion purposes only and does not represent the findings or recommendations of the Commissioner.

Procedures

We reviewed the literature on regulatory mechanisms governing the protection of water quality and public health. The literature was selected to cover those public documents that describe policies, laws, regulations, and programs as they pertain to livestock waste and water. Information was selected to exclude impacts on water resources by agricultural contaminants that do not originate in livestock waste. In addition, documents that describe strategies and approaches for the selection of regulatory mechanisms were also included. Documents available to the public in electronic form through government sources were also considered.

Included in this report are regulatory policies governing manure management for water protection in jurisdictions including Quebec, New Brunswick, Ontario, New York State, Kentucky, and some European Union countries with a focus on the Netherlands. No attempt is made to evaluate these approaches. It is important to remember that what works well in one jurisdiction may not work at all in another. The reader is encouraged to keep in mind that the more strict regulatory approaches are not necessarily the most effective from the perspective of achieving set water quality goals at least cost to society. Similarly, what appear to be the least expensive approaches from a regulatory standpoint might actually be the most expensive from society's standpoint, if they are very inefficient at achieving water quality goals.

We also reviewed the literature on the biophysical aspects of manure handling, together with that on the presence of microbial pathogens and natural hormones in animal manure. We selected information that contributed to the understanding of those processes taking place during manure handling that affected the potential loading of contaminants at any time. Further selection focused only on aspects related to the potential for the contamination of drinking water. To meet the necessary time-lines, the depth of this review varied depending on the current information pertinent to Ontario. Original material has been included to provide clarification on factors affecting the potential for surface and groundwater contamination by materials from manure.

In evaluating manure production in Ontario, the focus has been on swine, dairy, beef, and all poultry enterprises. We developed estimates at the township level and aggregated them to the county and provincial scales. Forward projection has involved consultation with industry as well as evaluating the future demand for meat and animal products.

Background

As world demand for animal protein continues to increase, so too do the problems associated with handling manure, the byproduct of the livestock industry. The potential for environmental contamination from the large volumes of manure produced has been a major concern, and became a reality for the residents of Walkerton, Ontario, in May 2000.[1]

The issue for Walkerton residents was contamination of groundwater, which was used as a source of drinking water, with the bacterial pathogens *Escherichia coli* O157:H7, which causes hemorrhagic colitis and (in some patients) can result in hemolytic-uremic syndrome, and *Campylobacter jejuni*. In addition to pathogens, the water regularly showed elevated levels of nitrate.

Section 2 of this paper presents a thorough review of the regulations, policies, and management guidelines governing manure management and water protection. The goals of environmental regulations are:

- to provide private decision makers (whose actions contribute to water quality impairment) with the incentives necessary to consider the full cost of their production activities and

- to achieve specific water quality goals at the least cost to society, including producers and regulators.

Regulatory instruments include voluntary or non-voluntary, command-and-control or market-based approaches, design-based or performance-based instruments, and those that aim to distinguish between regulatory differences (point source or non-point source). Environmental regulations vary dramatically between regions. Those with more severe problems would be more likely to implement stricter, more expensive regulations, while regions with relatively minor problems might rely on less costly voluntary measures. However, most regions are introducing new, more stringent policy instruments.

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[1] M.H. Miller, 1991, "Environmental considerations in land application of animal manure-water pollution," *Proceedings of the National Workshop on Land Application of Animal Manure,* CARC, Ottawa, Ontario, June 11–12, p. 125; M.H. Miller, T.C. Martin, E.G. Beauchamp, R.G. Kachanoski, and H.R. Whiteley, 1990, *Impacts of Livestock Manure on Water Quality in Ontario: An Appraisal of Current Knowledge* (Guelph, ON: Centre for Soil and Water Conservation).

Regulatory Instrument	Description
Command and Control • Laws (legislative acts and zoning) • Standards (setbacks, public health rules/guidelines • Permits (by-laws, building permits) • Mandatory manure handling practices	• create a legally enforceable environment in which producers are expected to comply or face consequences of non-compliance
Market Instruments • Design-based (includes subsidies, low-interest loans, cost-sharing agreements, taxes, tradeable permits, manure rights, and quotas) • Performance-based (includes charges and subsidies, liability rules • Contracts, leases, and transferring manure rights	• attempts to influence producer decisions on the use of production inputs that are correlated to potential water quality impairment. • attempts to influence producer behaviour by the use of economic charges and subsidies indexed to regional ambient levels of pollutants. • creating and fostering markets for manure and treatment
Voluntary • Best management practices • Education • Certification • Farm plans	• any measure a producer may chose to participate in with no repercussion for non-compliance and no final incentives for compliance • regulation without education is less effective than a combined approach.

Successful policies are well-integrated combinations of individual components. Factors that determine the best mix of policies for any given area include:

- existing legislation and levels of government responsibility,
- the severity of existing water quality problems,
- costs imposed on society,
- costs of monitoring and enforcement,
- costs of providing necessary incentives for voluntary programs,
- watershed-specific geological features,
- costs to farmers for altering practices, and
- expectations of long-term industry trends.

In the late 1990s, a review of the state of U.S. water bodies estimated that one-third of all surface water continues to be affected by some degree of impairment. Surface runoff is now the most significant factor affecting water quality, and agriculture is the largest contributor to water pollution caused by runoff. Regulations aimed at reducing agricultural runoff would deliver a greater response at less cost than regulations aimed at industries causing point source water quality problems.

Section 3 presents an intensive review of the biophysical aspects of manure management in Ontario. Farm manure is a potentially valuable source of nitrogen, phosphorus, potassium, and other inorganic nutrients for plants. Organic carbon compounds in manure can be transformed by microbial activity into materials that are effective binding agents in the soil. Organic compounds in manure also enter the nutrient cycles within the soil in which nutrients are mineralized into forms that are readily available to plants. The sustainable use of resources requires that the most effective use be made of animal manure to enhance soil structure and productivity.[2]

But manure can cause contamination of groundwater. Potential contaminants include pathogenic microorganisms; nitrogen; phosphorus, which can cause eutrophication of fresh water; dissolved organic carbon, which contributes to turbidity in water; endocrine-disrupting compounds; and metals such as copper. Turbidity appears to be important for the survival of some pathogens in water supplies.[3]

Identifying the risk of environmental contamination from manure is complex. It is impossible to predict precisely what will happen to manure under any given set of conditions. Many factors impact the fate of manure constituents:

- the nature of manure itself, which varies considerably depending on the type, diet, and age of the livestock; the type of livestock housing and use of bedding; type and length of manure storage; and the method, timing, and rate of manure application on fields;

- the characteristics of the land receiving the manure, including soil texture, slope, depth to water table, proximity to water resources, and tillage; and

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[2] H. Kirchmann and E. Witter, 1992, "Composition of fresh, aerobic and anaerobic farm animal dungs," *Bioresource Technology,* 40, p. 137; A. Krogdahl and B. Dahlsgard, 1981, "Estimation of nitrogen digestibility in poultry: Content and distribution of major urinary nitrogen compounds in excreta," *Poultry Science,* 60, p. 2480; L.E. Lanyon and D.B. Beegle, 1989, "The role of on-farm nutrient balance assessments in an integrated approach to nutrient management," *Journal of Soil and Water Conservation,* 44, p. 164; N.K. Patni and P. Y. Jui, 1987, "Changes in solids and carbon content of dairy-cattle slurry in farm tanks," *Biological Wastes,* 20, p. 11; F.J. Stevenson, 1982, "Origin and distribution of nitrogen in soil," *Nitrogen in Agricultural Soils* (Madison, WI: American Society of Agronomy); A. Wild, 1988, "Plant nutrients in soil: Nitrogen," *Russell's Soil Conditions and Plant Growth,* 11th ed. (New York: Wiley), p. 652; J.C. Zubriski and D.C. Zimmerman, 1974, "Effects of nitrogen, phosphorus, and plant density on sunflower," *Agronomy Journal,* 66, p. 798.
[3] J. Aramini, M. McLean, J. Wilson, J. Holt, R. Copes, B. Allen, and W. Sears, 2000, *Drinking Water Quality and Health Care Utilization for Gastrointestinal Illness in Greater Vancouver,* <www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/vancouver_dwq.htm>.

- the weather (e.g., wind speed during application and rainfall intensity, frequency, and duration before and after manure application), which determines if potential contaminants move off-site in surface runoff, tile drainage flow, groundwater, or air or remain in the rooting zone where nutrients can be taken up by crops.

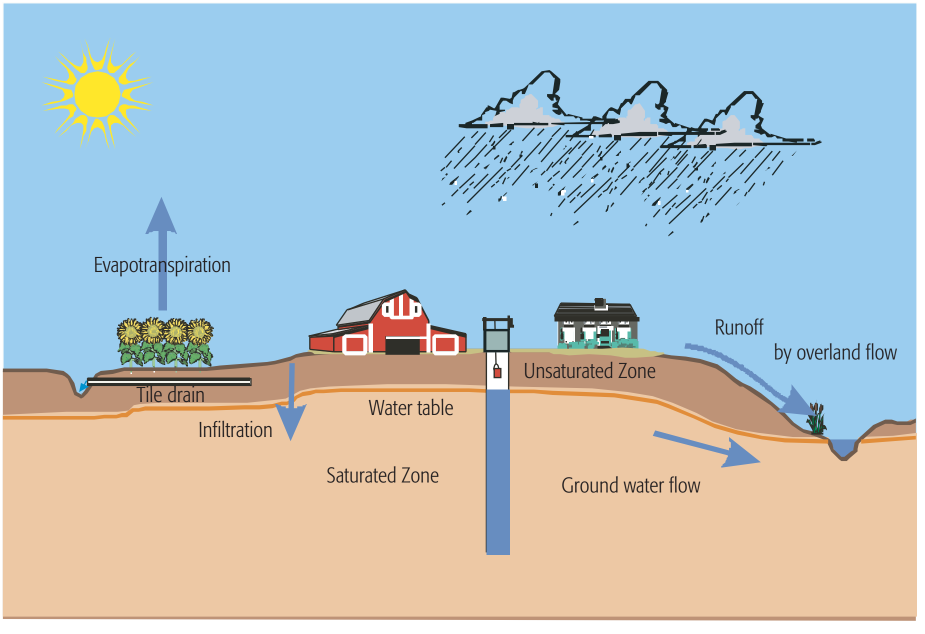
Two major water resources are recognized as sources of drinking water:

- surface water, which includes streams, municipal drains, rivers and lakes and

- groundwater, which consists of saturated zones in various strata of subsoil and rock.

The water or hydrological cycle (figure 1-1) is a major driver in determining the movement of contaminants. It affects the distribution of contaminants in the surface and groundwater as well as losses in gaseous form. The main components of the hydrological cycle are precipitation, evapotranspiration,

Figure 1-1 Schematic Diagram of the Hydrological (Water) Cycle



drainage, and runoff. The thirty-year average annual values for these components have been estimated for three sites in Southern Ontario (Harrow, Guelph, and Ottawa) and Kapuskasing in Northern Ontario (table 1-1).

Evapotranspiration, drainage, and runoff represent the fate of the precipitation component of the cycle. Averaged across the four Ontario sites, evapotranspiration accounted for 64% of precipitation, drainage 23%, and runoff 12%. Some of the drainage water moves laterally in the near-surface layer of the soil (interflow) and then to streams. Where tile drains are present, some proportion of drainage enters the drains and is consequently emitted to surface water instead of recharging groundwater.

Contaminants from manure can enter surface water bodies in the surface runoff from fields and yards, in interflow, in discharge from tile drains, and in groundwater. Contaminants enter groundwater by direct transport through rock and overlying soil or through man-made ducts such as abandoned, improperly sealed, or poorly maintained wells. In the process called leaching, materials are dissolved from the soil or rock as the water moves through.

Runoff in this document is restricted to mean surface runoff, but other authors have included interflow and discharge from tile drains as part of the runoff from agricultural land. Strictly speaking, surface runoff and direct entry into wells do not contain soil leachate, although some leaching will occur as rain or

Table 1-1 Annual Water Balance Components (mm) at Four Sites in Ontario for the Period 1961 to 1990 (average ± standard deviation)

	Harrow	Guelph	Ottawa	Kapuskasing
Precipitation	902±138	863±126	871±117	860±131
Evapotranspiration	675±68 74%	497±50 58%	562±38 64%	505±37 59%
Drainage	163±90 18% †	283±108 33%	201±137 23%	153±85 18%
Runoff	46±56 5%	81±64 9%	100±74 11%	206±53 24%

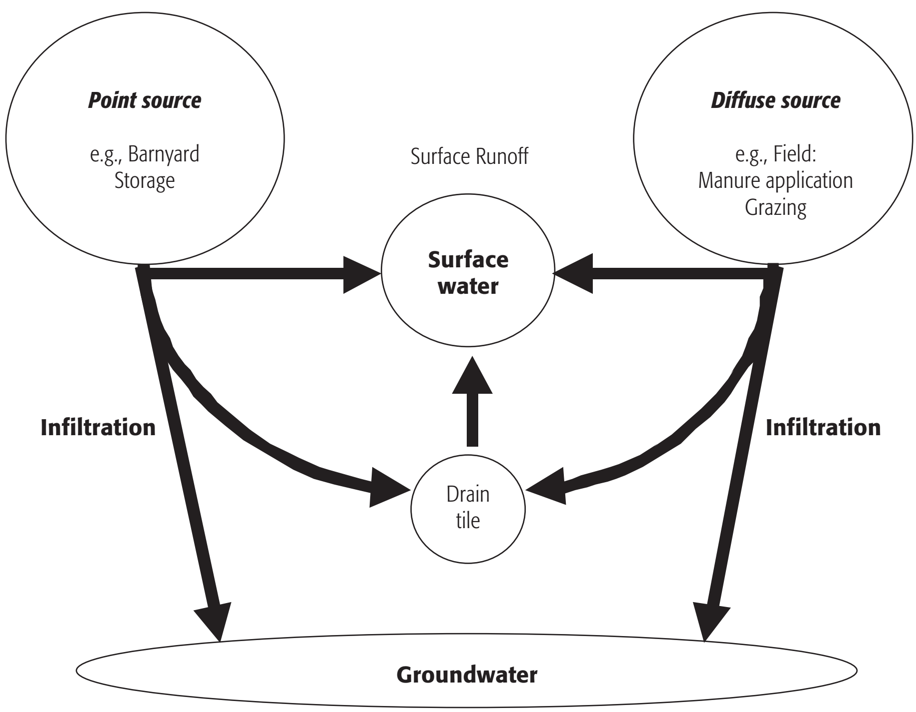
† Evapotranspiration, deep drainage, and runoff are also given as a percentage of precipitation.
Source: G.W. Parkin, C. Wagner-Riddle, D.J. Fallow, and D.M. Brown, 1999, "Estimated seasonal and annual water surplus in Ontario," *Canadian Water Resources Journal,* 24(4), p. 277.

meltwater moves to a surface or groundwater source via the other routes. Both surface and groundwater can therefore be impacted by runoff that picks up contaminants on the surface of the soil or on yards, as well as from manure that has been incorporated into shallow soil layers.

The ways in which potential contaminants can be lost from manure or made immobile greatly influence the likelihood that a given water resource may become affected. This is summarized in figure 1-2.

To assess the potential impact of manure on water quality, it is important to recognize the possibility for changes in the contaminant content at different stages of the management system. Pathogens may not survive a period of storage or the concentration of some nutrients may diminish. Nitrogen in manure is generally present in organic and inorganic forms. The main inorganic form is the ammonium ion, which can be transformed into ammonia and released as a gas or converted to nitrate (NO_3^-) with nitrite as an intermediate. Nitrite and nitrate

Figure 1-2 Schematic Diagram of the Sources and Movement of Contaminants from Manure to Water Resources



are of concern in potable water because of methemoglobinemia. Bacteria at the back of the tongue, or if present in the stomach, convert nitrate to nitrite. When nitrite enters the blood stream, it reacts with hemoglobin to form methemoglobin, which is incapable of releasing the bound oxygen for use in other tissues. This irreversible binding of oxygen to methemoglobin results in a cyanosis, which mainly affects newborn infants.[4] Such infants do not secrete sufficient acid into the stomach to give the pH of about 2 (high acidity) found in older people.

Agricultural land, particularly if it is under row crops or is used for intensive animal production, is often associated with groundwater having NO_3^- concentrations near or above 10 mg N/L.[5] In contrast, the upper limit of NO_3^- concentrations in groundwater not influenced by anthropogenic activity is considered to be 3 mg N/L.[6]

Gaseous losses of nitrogen lead to enhanced concentrations of ammonia and oxides of nitrogen in the atmosphere.[7] Ammonia release to the atmosphere has importance because it subsequently contributes to acidification of soils. Nitrous oxide (N_2O) is a potent greenhouse gas. Both gases are soluble in water. Ammonia can be returned in precipitation and, together with NO_2 (nitrogen dioxide), in dry deposition, thus adding to the soil mineral nitrogen fraction in an uncontrolled manner. Release of ammonia into the atmosphere through volatilization of fertilizer nitrogen and animal wastes is almost entirely due to agricultural activities. Ammonia is not a greenhouse gas. It is, however, of concern since releases of ammonia to the atmosphere have both local and long-

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[4] P. Fraser and C. Chilvers, 1981, "Health aspects of nitrate in drinking water," *The Science of the Total Environment,* 18, p. 103; R. Rajagopal and G. Tobin, 1989, "Expert opinion and groundwater quality protection: The case of nitrate in drinking water," *Ground Water,* 27, p. 835; A.P.S. Terblanche, 1991, "Health hazards of nitrate in drinking water," *Water SA,* 17, p. 77.

[5] M.J. Goss, D.A.J. Barry, and D.L. Rudolph, 1998, "Groundwater contamination in Ontario farm wells and its association with agriculture: 1. Results from drinking water wells," *Journal of Contaminant Hydrology,* 32, p. 267; J.D. Toth and R.H. Fox, 1998, "Nitrate losses from a core-alfalfa rotation: Lysimeter measurement of nitrate leaching," *Journal of Environmental Quality,* 27, p. 1027.

[6] R.J. Madison and J.O. Brunett, 1985, "Overview of the occurrence of nitrate in groundwater of the United States," *National Water Summary 1984*, USGS Water Supply Paper No. 2275 (Washington, D.C.: U.S. Govt. Printing Office), p. 93.

[7] C.B. Kresge and D.P. Satchell, 1960, "Gaseous loss of ammonia from nitrogen fertilizers applied to soils," *Agronomy Journal,* 52, p. 104; J.W. McGarity and J.A. Rajoratham, 1972, "Apparatus for the measurement of losses of nitrogen as gas from the field and simulated field environments," *Soil Biology & Biochemistry,* 4, p. 1; J.A. Ryan and D.R. Keeney, 1975, "Ammonia volatilization from surface applied sewage sludge," *Journal (Water Pollution Control Federation),* 47, p. 386; J.A. Ryan, D.R. Keeney, and L.M. Walsh, 1973, "Nitrogen transformations and availability of an anaerobically digested sewage sludge in soil," *Journal of Environmental Quality,* 2, p. 489.

range effects. Locally, impingement with crops and other vegetation may give rise to foliar damage. At longer range, ammonia deposition gives rise to nitrogen inputs with eutrophication effects on sensitive ecosystems.[8] Ammonia also plays an important role in the atmospheric chemistry of sulphur dioxide as it increases the loading rate of SO_2 in cloud water droplets, thereby contributing to acidification of soils and surface waters.[9] Ammonia is also involved in reactions with other pollutants, such as oxides of nitrogen (NO_x), in the atmosphere. Ammonia dissolved in surface runoff from yards or manure stores can enter surface water and negatively impact aquatic life.

Phosphorus in manure does not pose a direct threat to humans. However, when it enters freshwater bodies it enriches them, making them more productive – a process known as eutrophication. The effect is to increase the growth of algae within the habitat. The death of these algae and their breakdown by microorganisms can greatly deplete the oxygen concentration in the water so that the animal population is subject to oxygen deprivation. In extreme conditions fish can be asphyxiated.[10] Blue-green algae (cyanobacteria) grow rapidly in the presence of phosphorus. Some of these organisms produce toxins that can cause illness in humans. Although it is unlikely that drinking water containing the toxins would result in acute illness, long-term exposure may be associated with the development of cancer.[11]

Some metals, such as copper (Cu) and zinc (Zn), are used to promote growth in animals, but their concentration in drinking water is restricted mainly for aesthetic reasons.

Although metals and nutrients such as phosphorus are not lost from manure in gaseous form, the breakdown of organic carbon compounds during storage can greatly decrease the dry matter content of the manure. Hence, the final concentration of contaminants per unit weight of dry matter can be much greater

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[8] M.A. Sutton, C.J. Place, M. Eager, D. Fowler, and R.I. Smith, 1995, "Assessment of the magnitude of ammonia emissions in the United Kingdom," *Atmospheric Environment,* 29, p. 1393.
[9] H.M. ApSimon, M. Kruse, and J.N.B. Bell, 1987, "Ammonia emissions and their role in acid deposition," *Atmospheric Environment,* 21, p. 1939.
[10] P.A. Chambers, M. Guy, E.S. Roberts, M.N. Charlton, R. Kent, C. Gagnon, G. Grove, and N. Foster, 2001, *Nutrients and their Impact on the Canadian Environment* (Ottawa: Agriculture and Agri-Food Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada, Natural Resources Canada, Public Works, and Government Services Canada), p. 233.
[11] W.W. Carmichael, 1994, "The toxins of cyanobacteria," *Scientific American,* January, p. 78; I.R. Falconer, 1991, "Tumor promotion and liver injury caused by oral consumption of Cyanobacteria," *Environmental Toxicology and Water Quality,* 6, p. 177.

when manure is applied to land than it was at the time of excretion. Manure treatment by composting has a similar result. Appropriate application rates may therefore need to be relatively small, less than equipment can deliver reliably.

Fecal coliform, streptococci, and sometimes salmonella are the main pathogenic bacteria of concern. Important protozoan pathogens include *Cryptosporidium* and *Giardia*. The more animals on a farm, the greater the likelihood of pathogens in the manure. The survival of non-indigenous bacteria following land application of manure depends on soil pH, soil water content, organic matter content, soil texture, temperature, availability of nutrients, adsorption properties of the soil, and biological interactions in the soil (earthworms can reduce bacteria populations). Populations of microorganisms are dynamic – they are influenced by factors that affect their survival. Many are also motile.

Farm animals also excrete natural hormones, such as estrogen and progesterone, which are known to affect human development through interference with endogenous production and action. Hormone implants are also used to increase growth rates, and the metabolic breakdown products are also excreted. Antibiotics are applied to treat disease, but may also be given prophylactically in feed. These compounds can also be excreted, but little has been written about their transfer to water resources.

Of the 229 listed spills recorded by the Southwestern Region of the Ontario Ministry of the Environment, 17% were attributed to problems with manure storage. Where storages hold less than 180 days worth of manure production, manure is often spread on partly frozen ground, which risks endangering surface water supplies. Manure storages themselves, either earthen or concrete, in areas with shallow bedrock, pervious soils, or shallow water tables, can endanger water supplies. However, as long as Ontario guidelines for construction are followed, the self-sealing nature of manure can prevent major contamination from small cracks. Problems can become acute, however, if the leak intercepts an unsealed tile drain. Manure can then move directly to a water course. If leaks have occurred, the time of major concern is when the structures are decommissioned. The water in stored manure will help maintain saturated conditions in the soil near the point of the leak. As the soil dries after storage stops, ammoniacal nitrogen can be nitrified and organic nitrogen mineralized, resulting in nitrate that can then move to the groundwater.

The movement of liquid manure to tile lines is the most frequently reported type of manure spill. Researchers have documented the movement of liquid manure to tile lines through macropore or preferential flow. In this process, water and its constituents move by preferred pathways through a porous medium. It means that part of the matrix is effectively bypassed, as flow occurs through large pores and channels in the soil created by earthworms, roots, freeze-thaw, and cracking. Macropores have been shown to allow manure liquids to move to subsurface drains within an hour of application. One study showed that as a result of preferential flow, 96% of the infiltrating water moved through only 0.32% of the soil volume. Preferential flow occurs when rainfall or the liquid application rate exceeds the infiltration rate of the soil or when the soil is already saturated at the time of the rainfall or application. Flow through the larger macropores occurs much more quickly than through smaller pores.

Pre-tillage (tilling the land prior to manure application) has been shown to limit macropore flow by severing the continuous cracks, worm holes, root channels etc. Pre-tillage tines have been added to injection machinery to achieve the same effect. Some no-till farmers who want to preserve the beneficial soil conditions created by continuous no-till systems on their land, argue that it should be sufficient to till a swath over the tile lines while leaving the area in between undisturbed. This area needs to be addressed by further research.

Equipment manufacturers have been working on ways to reduce compaction caused by large tankers. Compaction can encourage surface runoff of manure, which may then enter adjacent water courses. Manufacturers have also been improving the uniformity with which liquid manure is spread. Uniform distribution is essential if farmers are to rely solely on the nutrients contained in manure for their crop’s nutrient needs.

In addition to the choice of application method, producers also have to make decisions on the timing of their land application. Factors to consider include the risks from soil compaction, likelihood of runoff, and nutrient loss though ammonia volatilization. The timing of manure applications is critical for the availability of nitrogen both to crops and on the potential for environmental impacts. As manure storage on many farms is limited, the common periods for application are the fall, winter, and spring. In spring, applications may be as a pre-plant fertilization or as a side- or top-dressing. The experimental evidence shows that compared with spring applications, manuring land in fall or winter results in lower recovery of applied nitrogen by the crops, greater risk of leaching and denitrification, and longer survival of bacteria.

Although it is impossible to accurately predict the fate of manure constituents following land application of manure, the development and use of agricultural best management practices minimize the risk of environmental contamination.

Significant research is needed in the field of manure management if water resources are to be protected from contaminants originating in manure. Both basic and applied research is required as well as machinery development. These needs cover aspects of:

- feeding regimes
- animal husbandry
- manure treatment
- field application

Section 4 provides an overview of manure production in Ontario in terms of distribution, volume, and spreading practices. Statistics Canada census data and livestock inventory numbers show current manure production levels. Future industry growth and manure management technologies are discussed.

About 67% of Ontario's agricultural sales comes from 20% of its farms, i.e., farms with annual gross revenue greater than $250,000. The majority of Ontario's livestock farms are located in the OMAFRA's Southern and Western regions.

Based on 1996 estimates, cattle produced 63% of the manure, swine 31%, and poultry 6%. Estimated manure production for the whole province declined by 7.5% between 1986 and 1996. Poultry manure production increased by 13.8% while cattle and swine decreased by 8.3% and 9.3% respectively. Manure production is projected to drop by 12% by 2010.

Based on 1996 census data, the top five counties in terms of manure production are Perth, Huron, Wellington, Oxford, and Bruce. Provincially, 19% of the tillable land receives manure. Even in Perth County, which has a relatively high livestock concentration, only 30% of the tillable land receives manure. If all of Ontario's agricultural land could receive equal amounts of manure, Ontario could support a much larger livestock industry. However, given current manure technologies and its current economic value, it is not feasible to transport manure over long distances.

Section 4 discusses how to balance society's need for safe, high-quality potable water with the needs of livestock farms to remain competitive and not be unduly burdened with extensive regulations.

2 Regulations, Policies, and Management Guidelines Governing Manure Management and Water Protection

2.1 Introduction

This section provides a comparative summary of the regulations governing manure management for water protection. The scope includes Quebec, New Brunswick, Ontario, New York State, Kentucky, and some European Union countries with a focus on the Netherlands. These jurisdictions were selected because they have similar geographical features to those of Ontario, similar legal and institutional frameworks, or a variety of regulatory devices that have been recently developed to take into account specific challenges associated with manure management and water protection.

Market forces, technological changes, and industry restructuring continue to cause significant changes in the livestock industry. One result of these changes is a trend toward a concentration of livestock and poultry production in all the major livestock producing nations, and a commensurate geographic concentration of livestock waste products. Concerns about environmental impacts have arisen in most of the affected countries, especially in areas where the environmental capacity to absorb the additional nutrients is limited.[12] Accordingly, most livestock-producing jurisdictions have developed and enacted new policies to control environmental impacts. While many of the new policies rely, in part, on pre-existing regulatory mechanisms, there is a clear and growing trend towards evaluating policy needs to specifically target livestock waste management. The published literature includes several studies that compare the efficacy of various policy instruments with regard to features such as impact on pollution levels, costs of implementation, effect on the industry, and institutional requirements for successful implementation. Policy mechanisms have also been compared across different industries and water impairment sources.

From examining the research and practices in this area, one can conclude that:

- a successful policy is made up of a well-integrated combination of individual components,
- no one policy is optimal for all situations, and

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[12] U.S. General Accounting Office (USGAO), 1999, *Animal Agriculture: Waste Management Practices*, (Washington, D.C.).

- a specific component that works well in one context may be inadequate in another.

Jurisdictions vary in how the different levels of government interact. The level and type of authority exercised by each level of government differs when dealing with the severity of water impairment problems. Differences across regions also exist in other factors, such as geological and physical features, the costs of complying with a given standard or practice, demographics, and other social and economic activities that may mitigate or exacerbate water quality issues associated with animal agriculture.

Section 2 is divided into several subsections. The goals of regulatory policy, in the context of livestock waste management are discussed in section 2.2 which also considers a number of reasons why policies and regulatory mechanisms that are targeted to similar goals can exhibit such a variety of differences. Results of studies that analyze differences between policy approaches are summarized. Several examples illustrate basic points, but details of these examples are left for later subsections that describe specific policies used in the various jurisdictions.

The jurisdictional reviews start with the United States (section 2.3), which has seen several new initiatives to regulate animal waste impacts on water in the last five years alone. Development of these initiatives has been coordinated among the different branches of government and levels of government, including the U.S. Environmental Protection Agency (USEPA) and the Department of Agriculture (USDA). Such coordinated and integrated efforts have not yet been seen to the same scale in Ontario.

Section 2.4 discusses regulations in selected jurisdictions in Europe, where the European Union (EU) helps to play an integrating role. European policies in general are more stringent than those in Canada and the United States, in part because the severity of existing water quality problems is greater. It means that to meet similar ambient nutrient standards, many European nations have to make bigger improvements, and that the waste per animal unit can create greater environmental stress than is the case in North America. European policies are especially interesting in that they tend to rely on a combination of market-oriented regulatory mechanisms.

Section 2.5 reviews the approaches of New Brunswick (which has a relatively new set of policies), Quebec, and Ontario. Ontario is considered last so that there is a context for the reader to consider the existing approach in this province relative to potential alternatives. Ontario has yet to see implementation of new regulations that specifically target livestock waste management for water resource protection. The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) recently initiated a process to review existing policies. The Ontario subsection concludes with a list of existing best management practices that are currently recommended for livestock producers in the province.

2.2 Goals of Regulation and Types of Regulatory Devices

Regulatory approaches vary widely across jurisdictions and, due to the industry trend toward concentration, have recently undergone significant changes within jurisdictions. In their assessment of the impacts of regulation on the hog industry in several European nations and 25 U.S. states, Beghin and Metcalf review recent trends in new environmental regulations aimed at livestock waste management.[13] Their review emphasizes "the evolving and heterogeneous nature of environmental regulation, which varies dramatically from state to state and across countries. Despite the geographical disparity in regulations, there is everywhere a common trend toward introducing more stringent and new policy instruments."[14] Table 2-1 illustrates the variety in type and stringency of regulatory mechanisms across the jurisdictions included in their study.

2.2.1 Goals of Regulation

The conceptual basis of environmental regulation is to provide private decision makers, whose actions contribute to water quality impairment, with the incentives necessary to consider the full cost of their production activities. Water quality impairment can impose costs on all members of society. These costs include increased municipal water treatment costs, costs of greater risk of illness caused by changes in water quality, and costs to society from loss of fish and wildlife habitat. In many cases, producers are unaware of the full extent of these costs and have little incentive to consider them as they do other production

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[13] J. Beghin and M. Metcalf, 2000, "Market hogs? An international perspective on environmental regulation and competitiveness in the hog market," *Choices*, First Quarter, p. 28.
[14] Ibid.

Table 2-1 Environmental Stringency Ranking of Environmental Regulations for the Hog Industry

Jurisdiction	Types of Regulatory Instruments Used
Very Restrictive	
The Netherlands	MPRs (Manure production rights), ammonia rights, nutrient standards for phosphate and nitrogen, nutrient management plan, facility design requirements, waste system approval, setbacks, reduction in MPRs, reduction of output, taxes on excess nutrients, scheduling and technical restrictions on manure spreading, odor permit.
Denmark	Nutrient standards for nitrogen, restrictions on spreading techniques and scheduling, facility design and waste system requirements and approval, setbacks, nutrient management plan, fines on excess nutrient, land cover requirements, land ownership requirement increasing with farm size, moratorium on farms exceeding 15,000 head.
Georgia	Local regulations, public hearings, geological testing, strict setbacks, facility and waste system approval, fees, nutrient standards, groundwater monitoring, discharge requirements exceed EPA criteria.
Kansas	Public hearings, setbacks facility approval, waste system approval, fees, nutrient standards bonding, groundwater monitoring, discharge requirements, required training.
Maryland	Local regulation, public hearings, geological testing, setbacks, facility and waste system approval, fees, nutrient standards, bonding, groundwater monitoring, discharge requirements, required training.
Iowa	Public hearings, geological testing, strict setbacks, facility approval, extensive waste system approval, fees, nutrient standards, groundwater monitoring, discharge requirements exceed EPA criteria, required training.
South Carolina	Public hearings, geological testing, strict setbacks, approval for facility, extensive waste system approval, fees, nutrient standards, groundwater monitoring, discharge requirements exceed EPA criteria, required training.
South Dakota	Local regulation, public hearings, geological testing, setbacks, facility and waste system approval, fees, nutrient standards, groundwater monitoring, discharge requirements exceed EPA criteria, required training.
Restrictive	
Belgium	Nutrient standards for nitrogen and phosphate, facility and waste system approval, manure shipping for non-family farms, restrictions on manure spreading techniques and scheduling, nutrient management plan, taxes on excess nutrient.
Arkansas	Public hearings, geological testing, setbacks, facility and waste system approval, fees, nutrient standards, discharge requirements exceed EPA criteria, required training, moratorium.
Illinois	Public hearings, geological testing, setbacks, waste system approval, fees, nutrient standards, bonding, groundwater monitoring, discharge requirements exceed federal EPA criteria, required training.
Indiana	Local regulation, geological testing, setbacks, facility and waste system approval, fees, nutrient standards, discharge requirements.
Kentucky	Geological testing, setbacks, facility and waste system approval, fees, nutrient standards, discharge requirements, moratorium.

Table 2-1 Environmental Stringency Ranking of Environmental Regulations for the Hog Industry, cont'd.

Jurisdiction	Types of Regulatory Instruments Used
Restrictive (continued)	
Minnesota	Local regulation, geological testing, setbacks, facility and waste system approval, nutrient standards, groundwater monitoring, discharge requirements, moratorium.
Mississippi	Local regulation, public hearings, geological testing, setbacks, facility and waste system approval, nutrient standards, discharge requirements, moratorium.
Missouri	Local regulation, public hearings, geological testing, setbacks, facility and waste system approval, fees, nutrient standards, bonding, groundwater monitoring, discharge requirements, required training.
North Carolina	Local regulation, public hearings, setbacks, facility and waste system approval, fees, nutrient standards, discharge requirements, required training, moratorium.
Ohio	Public hearings, geological testing, setbacks, facility and waste system approval, fees, nutrient standards discharge requirements exceed EPA criteria.
Oklahoma	Public hearings, setbacks, facility and waste system approval, fees, nutrient standards, bonding, groundwater monitoring, discharge requirements exceed EPA criteria, required training, moratorium.
Oregon	Geological testing, setbacks, facility and waste system approval, fees, nutrient standards, groundwater monitoring, discharge requirements exceed EPA criteria.
Pennsylvania	Local regulation, geological testing, setbacks, facility and waste system approval, nutrient standards, groundwater monitoring, discharge requirements exceed EPA criteria, required training.
Tennessee	Public hearings, geological testing, setbacks, facility and waste system approval, fees, nutrient standards, discharge requirements, required training.
Virginia	Local regulation, public hearings, facility and waste system approval, fees, nutrient standards, groundwater monitoring, discharge requirements, required training.
Moderate	
Taiwan	Waste system approval and requirements, concentration standards for waste pollution (BOD, COD, SS), manure spreading prohibited, zoning.
Arizona	Local regulation, geological testing, approval for waste system, nutrient standards, discharge requirements.
Colorado	Local regulation, setbacks, groundwater monitoring, discharge requirements, local level moratorium.
Nebraska	Local regulations, public hearings, geological testing, setbacks, facility approval, fees, nutrient standards, groundwater monitoring, discharge requirements.
Negligible	
Poland	
New York State	Local regulation, discharge requirements.

Source: Beghin and Metcalf, 2000.

costs. The role of well-designed regulatory instruments is to make these costs explicit to the producer, thereby providing the incentive to alter their practices and reduce potential financial costs. As a result, water quality impairment can be reduced.

As an ideal, a perfect regulatory instrument would increase the producer's marginal cost of water impairment by exactly the marginal cost that is imposed on society. In this way, the cost of water impairment would be treated as any other cost of production, and producers would choose practices that result in optimal levels of water quality for society.[15] In reality, it is often not possible for regulators or producers to determine the exact costs imposed on society as a result of the activities of a given producer. In addition, regulation imposes additional costs on society: administrative, monitoring, and enforcement costs. Therefore, a more realistic goal of environmental policy and regulation is to achieve specific water quality goals at least cost to society, including producers and regulators. Much of the economics literature about the environmental regulation of agriculture assumes this practical goal. The objective of many empirical studies is to determine least-cost approaches to achieving set environmental goals.[16]

The relative severity of regional water quality problems affects the regulatory goals and the types of regulatory instruments needed to achieve those goals. The variable of concern is not necessarily the water quality standard that is set, but the magnitude of the difference between existing quality and the standard, as well as the costs of achieving incremental improvements. Regions with more severe problems would be more likely to implement stricter, more expensive regulations, while regions with relatively minor problems might rely on less

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[15] Thus, well-designed regulations would not necessarily have zero-impact on water quality as a goal, but rather would act to strike a balance between society's costs for food production and the benefits of improved water quality.

[16] R.A. Fleming, B.A. Babcock, and E. Wang, 1998, "Resource or waste? The economics of swine manure storage and management," *Review of Agricultural Economics,* 20, p. 96; R.A. Kramer, W.T. McSweeny, W.R. Kerns, and R.W. Stavros, 1984, "An evaluation of alternative policies for controlling agricultural nonpoint source pollution," *Water Resources Bulletin,* 20, p. 841; A. Lintner and A. Weersink, 1996, *Evaluating Control Instruments for Improving Water Quality from Multi-contaminants in an Agricultural Watershed* (Guelph, ON: Department of Agricultural Economics and Business, University of Guelph); M. Ribaudo, R.D. Horan, and M.E. Smith, 1999, *Economics of Water Quality Protection from Nonpoint Sources: Theory and Practice* (USDA/Economic Research Service, Publication 782); D. Rigby and T. Young, 1996, "European environmental regulations to reduce water pollution: an analysis of their impact on UK dairy farms," *European Review of Agricultural Economics,* 23, p. 59.

costly, voluntary measures. The principal is that the poorer the existing water quality, the greater the cost to society of an additional unit of waste material. Therefore, in areas of Europe where water quality is already stressed by activities of the densely concentrated human population, the waste products of an additional animal unit impose greater water quality costs than in many regions of North America, which have yet to experience the same overall levels of stress to water quality. This trend is also apparent as changes within regions over time. Thus we see that in the last decade, the industry tended toward increasingly concentrated livestock facilities, and new regulatory measures, aimed at reducing the impact of livestock agriculture on water quality, have also increased. The rates at which different jurisdictions develop new guidelines vary, due to the change in development of the industry among regions, the physical features of the watersheds, other human activities that affect regional water quality, and changes in the uses of local water supplies.

Often, a jurisdiction may have focused heavily on reducing water quality impairment from specific sources over time. As a result, the additional benefit to society from increasing stringency of regulation for those sources becomes quite small relative to increasing the focus on other sources, which had previously not received the same level of attention. This principal is seen in the United States where, for the two decades after the *Clean Water Act* was initially enacted in 1977, regulators focused on point source pollution from industrial and municipal effluent. By the late 1980s, a formal review of the state of the nation's waters estimated that one-third of all surface water continues to be affected by some degree of impairment, but that surface runoff was the single most significant factor affecting water quality.[17] Agriculture has generally been recognized as the largest contributor to water pollution caused by runoff in the United States.[18] Therefore, the costs of regulation aimed at reducing runoff from agricultural operations would, at the margin, be expected to deliver a greater response than regulatory actions with similar costs aimed at industries causing point source water quality problems. It is not surprising, therefore, that in the last decade important new regulatory and market-based initiatives

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[17] U.S. General Accounting Office (USGAO), 1999.

[18] Ibid; U.S. Environmental Protection Agency (USEPA), Office of Water, 1999a, *B1. Management Measure for Facility Wastewater and Runoff from Confined Animal Facility Management (Large Units)* [online], [cited: last updated Oct 4, 1999], <www.epa.gov/OWOW/NPS/MMGI/Chapter2/ch2-2b1.html>; U.S. Environmental Protection Agency (USEPA), Office of Water, 1999b, *B2: Management Measure for Facility Wastewater and Runoff from Confined Animal Facility Management (Small Units)*, [online],[cited February 12, 2002], <www.epa.gov/OWOW/NPS/MMGI/Chapter2/ch2-2b2.html>.

have been developed in the United States to reduce the impacts of livestock agriculture on water quality.

2.2.2 Types of regulatory instruments

There are a wide variety of regulatory instruments and the various studies use different criteria to classify them. Criteria include voluntary versus non-voluntary instruments,[19] command-and-control regulation versus market-based approaches, design-based versus performance-based instruments,[20] and those studies that aim to distinguish between regulatory differences presented by point source versus non-point source pollution.[21] However, underlying most analytical frameworks is some measure of the incentive necessary for producer compliance as compared with the level of water quality change achieved and other regulatory costs.

Existing policy instruments range from those that produce relatively weak incentive mechanisms, such as education programs that attempt to use moral suasion to induce producers to voluntarily alter practices, to those with strong incentive mechanisms, such as issuing permits only after provision of proof that practices have been altered, levying fines for failure to comply with recommended practices, and charging fees for increasing livestock holdings. Policies with weaker incentive mechanisms are often less costly to administer: monitoring costs may be small or absent, and enforcement costs are, by definition, lacking entirely. Conversely, stricter regulations incur greater administrative and monitoring costs and include costly enforcement mechanisms. Innovations that reduce these associated regulatory costs can alter the feasibility of different mechanisms.

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[19] N. Anders Norton, T.T. Phipps, and J.J. Fletcher, 1994, "Role of voluntary programs in agricultural nonpoint pollution policy," *Contemporary Economic Policy,* XII, p. 113; D.J. Bosch, Z.L. Cook, and K.O. Fuglie, 1995, "Voluntary versus mandatory agricultural policies to protect water quality: Adoption of nitrogen testing in Nebraska," *Review of Agricultural Economics,* 17, p. 13; D.P. Stonehouse, 1996, "A targeted policy approach to inducing improved rates of conservation compliance in agriculture," *Canadian Journal of Agricultural Economics,* 44, p. 105.

[20] A. Conway, 1991, "A role for economic instruments in reconciling agricultural and environmental policy in accordance with the Polluter Pays Principle," *European Review of Agricultural Economics,* 18, p. 467; A. Weersink and J. Livernois, 1996, "Introduction," in *Exploring Alternatives: Potential Application of Economic Instruments to Address Selected Environmental Problems in Agriculture.* Edited by A. Weersink and J. Livernois (Ottawa: Environment Bureau, Agriculture and Agri-Food Canada).

[21] Kramer et al., 1984; M. Ribaudo and R.D. Horan, 1999, "The role of education in nonpoint source pollution control policy," *Review of Agricultural Economics,* 21, p. 331.

2.2.2.1 *Command-and-control direct regulation*

Command-and-control regulations create a legally enforceable environment wherein producers are expected to comply with a standard practice or face consequences if they are found to be in non-compliance. Generally, direct regulation implies that the standard is applied at the individual level and is the same for all producers, and that monitoring and enforcement are feasible. An example is the U.S. *Clean Water Act*, which classifies Concentrated Animal Feeding Operations (CAFOs) in the same manner as point source industrial and municipal polluters. Point source polluters are generally held to strict zero-tolerance rules and must apply for permit renewal every five years. An exception is made for CAFOs in the special circumstances of a 25-year 24-hour storm event, when the owner or operator would not be held liable for water quality impairment. Otherwise, permits are not granted unless the operation can produce evidence that its activities do not impair water quality. In this case, the burden of proof is on the permit applicant, and non-compliance could result in fines or closure of an operation.[22] Because many water quality impairment problems emanating from livestock waste management are characterized by its diffuse non-point nature, use of direct regulation is limited and, as a stand-alone mechanism, is unlikely to achieve regulatory objectives.[23]

2.2.2.2 *Voluntary approaches*

Voluntary approaches include educational programs to raise producer awareness of their impacts on water quality on-farm and off-farm and development of 'codes of practice,' which specify combinations of best management practices (BMPs) that are consistent with reducing water impairment in a given region. It is generally recognized that the effectiveness of such programs is limited to those situations in which the recommended practices can achieve water quality goals without affecting on-farm profit. Given that off-farm impacts on water quality are generally greater than on-farm impacts, the situations in which voluntary programs alone would be effective are quite rare.[24] Therefore, many voluntary programs include subsidies to increase the incentives for compliance.[25] In this case, the farmers for whom compliance would be least costly are those most likely to participate. However, these farmers may not be those whose

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[22] The *Clean Water Act*, definitions of CAFOs, and terms of permits are discussed later.
[23] Stonehouse, 1996; Ribaudo, Horan, and Smith, 1999; Weersink and Livernois, 1996.
[24] Anders Norton, Phipps, and Fletcher, 1994; Ribaudo, Horan, and Smith, 1999.

change in practices would make the largest contribution to water quality improvement. In other words, resources spent on subsidies might be better employed otherwise to achieve the same goal. For this reason, Anders Norton et al. suggest that in cases where water impairment costs are mostly borne off-farm, policy-makers should prefer regulation or other alternatives.[26] Bosch et al. generally concur, but point out that their empirical research indicates that regulation without education is less effective than a combined approach.[27]

In situations where the greatest contribution to a local water quality problem is due to diffuse, non-point source runoff and the water quality costs are not severe, voluntary approaches are still popular when used in combination with other mechanisms. However, many approaches that are often classified as 'voluntary' actually include positive or negative incentive mechanisms to induce compliance. For example, in many jurisdictions including Ontario and many U.S. states, livestock producers who can demonstrate that they have used recommended codes of practice protect themselves from legal liability in any potential case where their diligence may have nevertheless resulted in unavoidable water quality impairment. Protection from liability carries a real value to producers and so provides an incentive to alter practices and maintain documentation.

In many jurisdictions, voluntary programs include measures that reduce costs to producers' for participation and altering practices. These typically consist of tax breaks and financial assistance to cover some part of those costs. An example is the USDA's Environmental Quality Incentives Program (EQIP), specifically designed to assist producers with the support necessary to alter production practices.

In all, U.S. federal agencies estimated that they spent $498.7 million, as well as providing technical assistance to producers for animal waste management during fiscal years 1996 through 1999.[28]

Voluntary approaches also include "cross-compliance" mechanisms, which typically tie a producer's access to other agricultural support programs to their participation in conservation programs. In the United States, where cross-compliance had been used for many years, recent trends in agricultural commodity

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[25] Kramer et al., 1984.
[26] Anders Norton, Phipps, and Fletcher, 1994.
[27] Bosch, Cook, and Fuglie, 1995.
[28] The EQIP program and others are discussed in more detail later in this chapter; USGAO, 1999.

income-support programs have weakened incentives to participate in environmental programs. In addition, uncertainty about the future of farm support programs due to domestic and international trade policy changes reduces the economic leverage that cross-compliance programs require. Finally, while farm income-support programs are diminishing, the importance of environmental programs to reduce off-farm costs of agriculture is increasing. In general, agricultural income and commodity policies have different purposes and goals from environmental regulation, and the economic inefficiencies and policy problems associated with combining them have brought many researchers to conclude that the future role of cross-compliance approaches will be limited in the United States.[29]

While voluntary approaches are subject to the above limitations, an important feature of water pollution caused by livestock waste is that much of it comes from non-point sources. This means that the effect of any given producer's actions on the overall level of water quality is not observable either by the producer or the regulator. The direct impact of a given activity by a given producer is affected by timing, duration and amount of rainfall, the water table, slope, proximity to waterways, location in a watershed, and numerous other geographic and physical variables that are affected by random climatic events. In many situations, no obvious cause and effect may be apparent between land-use activities and localized water quality problems. Thus, the best that one can do is to estimate the probability that a given activity will cause an impact and estimate the expected costs of the impact on water quality impairment. The informational problems create tremendous difficulties in regulatory design.[30] A single regulatory rule applied to every producer (perhaps with systematic and observable differences in producer type) will likely have different outcomes and be excessively expensive to monitor and enforce.

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[29] R.E. Heimlich and R. Claassen, 1998, "Agricultural conservation policy at a crossroads," *Agricultural and Resource Economics Review,* 27, p. 95.

[30] K. Segerson, 1988, "Uncertainty and incentives for nonpoint pollution control," *Journal of Environmental Economics and Management,* 15, p. 87; K. Segerson, 1990, "Incentive policies for control of agricultural water pollution," *Agriculture and Water Quality: International Perspectives* (Boulder, CO: Lynne Rienner), p. 39; R. Cabe and J. Herriges, 1992, "The regulation of nonpoint-source pollution under imperfect and asymmetric information," *Journal of Environmental Economics and Management,* 22, p. 134; J.B. Braden and K. Segerson, 1993, "Information problems in the design of nonpoint-source pollution policy," *Theory, Modeling and Experience in the Management of Nonpoint-source Pollution* (Boston: Kluwer Academic), p. 1; J.S. Shortle and D.G. Abler, 1994, "Incentives for nonpoint pollution control." *Nonpoint Source Pollution Regulation: Issues and Analysis* (Boston: Kluwer Academic), p. 137; Weersink and Livernois, 1996.

2.2.2.3 *Market-based economic instruments*

Because of the challenges presented by non-point source problems, some regulatory approaches attempt to use economic instruments that indirectly provide the farmer with the incentives necessary to alter manure-handling practices. This approach has received a tremendous amount of interest due to theoretical studies that suggest economic instruments can achieve a given environmental goal at a lower cost than other policy alternatives. Futhermore, it is used throughout Europe as a cornerstone for livestock waste management policies. Weersink and Livernois, and Braden and Segerson evaluate several economic instruments for their potential to reduce water pollution from agriculture.[31] Economic instruments are of two forms: performance-based and design-based.

Performance-based instruments are applied to target ambient levels of pollutants. Those feasible for livestock agriculture include charges and subsidies, based on the ambient environmental quality of the target water bodies or the watershed in a given region, and liability rules. The levels of the charges or subsidies depend on changes in ambient levels. As the measured ambient levels increase relative to water quality objectives, producer charges are increased. If ambient levels decrease below objectives, farmers may receive reward payments. Farmers compare their costs of complying with the potential costs of ignoring the ambient standards, and choose practices that are likely to maximize profit. Such a policy theoretically provides producers with the incentive to determine the lowest-cost practices for their operations to attain a given overall regional standard. The correlation between individual farmers' practices and ambient nutrient concentrations is greater, and the instrument more effective, when there are shorter time lags between on-farm activities and their associated effects on water quality and when the number of producers in the region is relatively small. However, in practice it is difficult to design and implement performance-based instruments in complex, multi-use watersheds.

Liability rules, as performance-based instruments, make producers responsible for the costs of any water quality damages that they cause. These are only suitable for cases in which there is clear evidence that a given water quality damage event can be traced to a specific producer, for example, when manure lagoons leak or overflow. But since most livestock waste and water quality problems are diffuse, liability rules are most useful as a complementary mechanism to other instruments.

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[31] Braden and Segerson, 1993; Weersink and Livernois, 1996.

Design-based instruments, which include subsidies for adopting more benign manure management or land-use management practices, tradeable permits, and charges on outputs, are intended to affect production decisions by targeting production inputs and outputs that are correlated with potential water quality damages. Targeted subsidies (grants, loans, and tax allowances) may be granted to producers who demonstrate that they have adopted management practices to reduce their contribution to water quality problems. As discussed above, subsidies have to be set at levels consistent with the corresponding impact on water quality goals. Otherwise a single rate for all producers may encourage some to incur costs that are more than the associated increase in water quality while providing too low an incentive to others who could have a relatively greater impact on water quality. Practical problems also include equity considerations in cases where producers who had already been using recommended practices are not eligible for subsidies that are intended as incentives to encourage those who are still using undesirable practices to change.

The associated instrument of a tax or a charge for practices and inputs that are considered detrimental to water quality objectives is considered to be problematic for several reasons, including the infeasibility of charging differential taxes to different producers based on farm type, region, and location in the watershed. These differentials may be considered unconstitutional in some jurisdictions, and producers may be able to substitute among inputs and practices to avoid the tax in ways that simply change the water quality problem without correcting it.[32]

Tradeable permits grant producers rights to produce at specific levels that are correlated with expected levels of non-point water quality impairment. For example, in the Netherlands, producers are granted Manure Production Rights (MPRs) based on historical farm production records and land holdings. Producers are able to buy and sell MPRs within regions, and between regions if the sale is from a manure-surplus region to a manure-deficit region. Some restrictions apply to markets for MPRs between livestock species and the government can impose a “fee” on each transaction (a percent of the MPRs traded). The effect of such a system is that farmers are allowed some degree of discretion in how they manage their individual transitions in production practices. Meanwhile the overall effect over time is to channel the market for

[32] Lintner and Weersink, 1996.

MPRs so as to achieve overall water quality goals within and between regions. The regulator can gradually reduce the number of MPRs in the system, thereby providing producers with a process that allows some individual adjustment over time.

2.2.3 The Role of Individual Producer Discretion

Regulatory instruments vary in the degree of individual choice given to the producer with regard to practices used to reduce impairment and the level of diligence. However, as discussed above, using approaches that allow for greater degrees of producer discretion does not necessarily imply that incentives are weaker. Market-based economic instruments can be used to achieve water quality goals in a given region while allowing producers the choice of how and when to alter practices to achieve these goals.

Livestock waste management plans in the United States are another approach that leaves some degree of producer discretion. These plans are developed by producers with the support of specially trained USDA soil-conservation-service staff members. These plans are developed to fit a combination of farm-specific and watershed-specific goals. In some states, such plans are required in order for producers to obtain permits for their livestock operations. The details of each plan can be tailored to meet waste-management objectives in ways that may differ substantially from farm to farm, yet be equally effective in reducing water quality impacts. The underlying idea is that so-called ‘best management practices’ are not necessarily ‘best’ in the sense of achieving water quality goals at least cost when applied to all farm operations. Differences in watershed features, farm locations, existing combinations of practices, and regional water quality needs and goals may result in different estimations of the ‘best’ combinations of practices at any given farm. An advantage of discretionary decision making is that farmers have incentives to innovate and find the most cost-effective means to meet regulated standards. Individual innovations contribute to technological advances that benefit the industry, while reducing water impairment costs to society. The existing Environmental Farm Plan program might be a starting point for similar regulatory programs in Ontario, although at this time Environmental Farm Plans are not required, nor are producers required to follow their plans.

2.2.4 Coordinated Strategies

There is an increasing trend toward the achievement of explicit water quality goals through strategic policies that incorporate combinations of mechanisms. The USEPA recommends that policies be developed and examined at regional levels.[33] Similarly, a main recommendation of the most recent review of the state of groundwater stocks and protection in the United States is greater coordination of policies among institutions, within and among levels of government, and across localities.[34] The regional and explicit watershed approach used at the federal and state levels is an example of coordination strategies. Federal cost-share programs have had a significant coordination impact both vertically between federal, state, and local levels of government, and to a lesser degree horizontally between land-use and water quality policies.[35]

An interesting example of local strategic water-quality-policy development is that of New York City. The purpose of the strategy was to maintain quality of drinking water supplies so as to meet federal standards mandated by the USEPA under authority of the *Safe Drinking Water Act*.[36] Failure to meet federal standards would require the city to implement expensive filter treatments or be found in non-compliance with federal law. The first step in the strategy was to conduct a systematic assessment of how existing regulations could be used to protect water in the source watersheds and to identify the gaps in the existing regulations, relative to their needs. Development of new mechanisms focused on those situations that were not already adequately covered, which included livestock waste handling by the region's dairy producers. New livestock waste management policies, developed as part of the strategy, are therefore integrated into an overall plan for water quality protection.

The type of strategy employed by New York City involves integrating policy in a systematic fashion over a combination of federal, state, county, and municipal levels of government. Different levels of government often have limited sets of

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[33] U.S. Environmental Protection Agency (USEPA), Office of Wastewater Management and U.S. Department of Agriculture (USDA), 1999, *U.S. Department of Agriculture/U.S. Environmental Protection Agency Unified National Strategy for Animal Feeding Operations, March 9, 1999* [online], [cited February 12, 2002] <www.epa.gov/owm/finafost.htm>.
[34] Ibid.
[35] C. Johns, 2000, *Non-point Source Water Pollution Management in Canada and the U.S.: A Comparative Analysis of Institutional Arrangements and Policy Instruments*, [unpublished dissertation, McMaster University].
[36] U.S. National Research Council (NRC), 1999, *Watershed Management for Potable Water Supply: Assessing the New York City Strategy,* Report by the Committee to Review the New York City Watershed Management Strategy (Washington D.C.: National Academy Press).

policy tools, which can overlap or leave gaps. For example, in Ontario, municipal governments may enact zoning by-laws, regulatory statutes are developed and implemented at the provincial level, and water quality guidelines are set at the federal level, which has limited authority to impose regulation. Overcoming institutional barriers to achieve a systematic approach to regulation can be a difficult and expensive process in itself. However, the administrative costs would be apportioned over the relative efficiencies gained in water quality protection from all types of impairments over the region for which the strategy is developed. Similarly, such a strategy is more likely to result in apportioning the private costs of regulation over the range of contributors to water quality impairment problems (consistent with the "polluter pays" principle).

Finally, it must be noted that well-designed policies can justifiably combine different regulatory instruments. The best combination of mechanisms for a given jurisdiction depends on many features, such as:

- existing legislation and levels of government responsibility,
- the severity of existing water quality problems,
- the costs imposed on society,
- the costs of monitoring and enforcement,
- the costs of providing necessary incentives for voluntary programs,
- watershed-specific geological features,
- the costs to farmers of altering practices, and
- expectations of long-term industry trends toward increasing concentration of livestock operations with attendant increases in the volumes of animal waste per unit land area.

Where the benefits of minimizing water quality impairment are very large and the desire to minimize risk is great, higher-cost regulatory devices are more justifiable. Where the cost of water quality impairment is less, the use of cheaper mechanisms with a larger voluntary component is more justified. In some cases, the costs of treating municipal water may be cheaper than developing and implementing policies to maintain water quality at levels that do not require treatment. In other cases, the opposite may be true.

Since regions differ in their characteristics, optimal livestock waste management policies will necessarily vary. Thus, while it is reasonable for a strategy to include a variety of regulatory instruments, the combinations of instruments is likely to differ among jurisdictions. The analogy is similar to the notion that the efficacy of individual farm-level management practices is difficult to assess without the context of the combination of practices that are used on the same farm, and the particular features of the region where the farm is located. Achieving a given water quality goal at least cost could be attained by vastly different combinations of practices at the farm level. Similarly, it is difficult to assess the effectiveness of a given regulatory instrument outside the context of its use, especially given the data limitations related to water quality that exist in most jurisdictions.

The remainder of this section reviews several approaches used by different jurisdictions. Different regions use different combinations of regulatory devices, voluntary approaches, and market-based mechanisms. The section describes what is in use today, according to written documentation, but does not attempt to evaluate which approaches are 'best.'

Some of these approaches result from recent policy assessments, which can be time-consuming, research-intensive, and expensive processes. Some regions, including Ontario, may not have yet undergone or completed such processes. But because one approach works in a particular region, it does not necessarily mean it is the optimal approach for another. So while it may be tempting to suggest that a particularly innovative idea that works in Europe might work as well in Ontario, such a conclusion is not justified without the appropriate investment in research of the the needs and circumstances that face Ontario producers and that apply to Ontario citizens who bear the costs of impaired water quality from livestock production. The reader is encouraged to keep in mind that stricter regulatory approaches are not necessarily the most effective from the perspective of achieving set water quality goals at least cost to society. Similarly, what appear to be the least expensive approaches from a regulatory standpoint might actually be the most expensive from society's standpoint, if they are very inefficient at achieving water quality goals. Reviewing different jurisdictions can provide some practical context by which to compare various regulatory devices, voluntary approaches, and market-based instruments and to consider their potential applicability in Ontario.

2.3 United States

Environmental impacts of livestock waste have recently received a lot of attention in the United States. During the latter half of the 1990s, federal and state governments initiated a number of studies to investigate the impacts of livestock operations on water quality and to assess the ability of existing regulations and strategies to control these impacts.[37]

This sub-section describes the basic structure of the federal and state laws that govern the regulation of water quality and the potential threat from manure handling, and concludes with brief summaries of New York State and Kentucky livestock waste policies. Kentucky was chosen because it has geological features similar to those in parts of Ontario, namely fissured limestone, which potentially allow surface water to affect groundwater stocks relatively more quickly than is typical. And like Ontario, the majority of rural and small-municipal water supplies in Kentucky come from groundwater. New York State has a similar livestock agricultural industry as Ontario and also shares a common border.

2.3.1 Overview of Relevant U.S. Environmental Regulations

The system of institutional and legal authority in the United States differs substantially from that in Canada. For example, the U.S. federal government has greater authority to enact laws that regulate activity within local jurisdictions than has the federal government in Canada. This structure allows a greater degree of coordination between jurisdictions than is typically seen in Canada. The greater level of federal authority in the United States generates greater federal responsibility and support for local programs. Federal power over water quality is, in part, mandated by the *Clean Water Act* and the *Safe Drinking Water Act*. The USEPA is authorized by Congress to ensure that the provisions of these Acts are met across the country. In general, all states must adhere to USEPA standards and regulations, through either direct USEPA administration or state administration under USEPA authorization. However, states may develop water quality and manure management standards and regulations that are stricter than the federal ones. For example, table 2-1 refers to states in which discharge requirements exceed USEPA criteria.

The U.S. *Safe Drinking Water Act (SDWA)* provides the authority for environmental regulations that directly target public health and the quality of

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[37] U.S. General Accounting Office (USGAO), 1995, *Animal Agriculture: Information on Waste Management and Water Quality Issues* (Washington, D.C.); USGAO, 1999; USEPA, Wastewater Management and USDA, 1999.

drinking water at or near the point of use. The U.S. *Clean Water Act (CWA)* focuses on the quality of source waters and discharges into those waters. The USEPA administers both acts. Within the considerations of the *CWA*, water quality programs are further divided into point source and non-point source programs.

The *SDWA*, passed in 1974, sets allowable maximum contaminant levels (MCLs) for finished drinking water. The safe water treatment rule (SWTR), under the *SDWA*, describes the criteria that must be met by surface water supplies that exempt them from expensive water filtration requirements. Most regulations specifically aimed at groundwater tend to fall under the authority of the *SDWA*.

The *Clean Water Act* requires U.S. waters to meet quality levels that are fishable and swimmable.[38] States must classify waters according to their use and set specific water quality criteria for those classifications. For waters not meeting the standards, the *CWA* requires that sources of pollution be identified, total maximum daily loads be developed, and mechanisms for reducing pollution be described.[39]

Point source pollution is defined in the U.S. *Clean Water Act* to include any "discernable, confined, and discrete conveyance" and specifically includes "concentrated animal feeding operations" (CAFOs). The definition of point source exempts agricultural stormwater discharges. This exemption does not apply when the discharge is associated with the land disposal of animal manure originating from a CAFO or is not the result of proper agricultural practices.

For water quality problems that are identified as point source in nature, the *CWA* authorizes the USEPA to administer the National Pollutant Discharge Elimination System (NPDES). The NPDES defines CAFOs as point sources, thus requiring such operations to qualify for permits that ensure that standards are maintained and best available control strategies are used.[40]

Technically, the term non-point source (NPS) is defined to mean any source of water pollution that does not meet the legal definition of point source in section 502(14) of the *Clean Water Act* of 1987. "Non-point source pollution results from precipitation, land runoff, infiltration, drainage, seepage, hydrologic

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[38] U.S. Environmental Protection Agency (USEPA), 1977, *Clean Water Act*, <www.epa.gov/region5/defs/html/cwa.htm> and <www.epa.gov/epahome/laws.htm>.
[39] U.S. NRC, 1999.
[40] Ibid.

modification, or atmospheric deposition. As runoff from rainfall or snowmelt moves, it picks up and transports natural pollutants and pollutants resulting from human activity, ultimately depositing them into rivers, lakes, wetlands, coastal waters, and groundwater."

Regulation that targets surface NPS pollution tends to fall under the authority of the *CWA*. Surface runoff from non-point sources has been identified as the current largest contributing factor to water quality problems in the United States, with livestock agriculture singled out as a significant problem. Although CAFOs fall under the NPDES permit program, the majority of livestock operations that contribute to runoff problems are smaller than the definition of a CAFO and are therefore not considered point sources and do not require permits. Several states have provided stricter definitions for granting permits to livestock operations.

In response to the Clean Water Action Plan released in 1998, the USEPA and the USDA developed a Unified Strategy to address livestock waste management.[41] The Strategy elaborates and strengthens the requirements for CAFOs that are regulated under NPDES permits, and provides numerous guidelines for voluntary measures for smaller operations. The voluntary programs are supported by a number of incentive mechanisms, including technical support, financial assistance, and limited liability for operators who demonstrate appropriate management measures. Details of this strategy are described later.

The distinctions between point source and non-point source, surface waters and groundwater, and drinking water quality protection for public health and water quality protection for broader environmental mandates can become rather vague in many places. Provisions of the *CWA* and *SDWA* may overlap or not provide even coverage. In such cases, individual states and municipalities may develop specialized strategies to achieve water quality protection goals. For example, the 1997 New York City Watershed Memorandum of Agreement (MOA) outlines the watershed management strategy that protects drinking water for nine million residents of New York City. The MOA creates watershed rules and regulations that "fill in the gaps between the *CWA* and the *SDWA*."[42] The MOA addresses non-point pollution generated by livestock agriculture within its Watershed Agricultural Program.

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[41] USEPA, Wastewater Management and USDA, 1999.
[42] U.S. NRC, 1999.

2.3.2 U.S. Regulations, Acts, and Programs Designed to Protect Groundwater

Federal financial and technical support to municipalities and states for developing groundwater protection plans is available through the *Safe Drinking Water Act* and the *Clean Water Act*. While the *CWA* targets surface waters, groundwater is included as it affects surface water through interconnected groundwater stocks. Provisions of the *CWA* that relate specifically to livestock agricultural wastes will be discussed in more detail below.

Section 1429 of the *SDWA* authorizes the USEPA to give grants to individual states for the development and implementation of groundwater protection programs.[43] The USEPA is required to evaluate state-funded programs and report to Congress every three years on the status of groundwater quality and on the effectiveness of state programs to protect groundwater. Amendments to the *SDWA* in 1996 authorized Congress to spend up to $15 million per year from 1997 through 2003 to support the state programs.[44]

As of 1999, 47 states had approved wellhead protection programs that are being expanded under the provisions of the 1996 *SDWA* amendments. Almost every state has begun to implement comprehensive groundwater protection programs, including enacting legislation and regulations, monitoring groundwater quality, developing data management systems, and implementing remediation and protection programs. The majority of federal funds allocated for groundwater have been devoted to remediation as opposed to planning or protection. The assessment of state programs resulted in recommendations for more effective coordination of groundwater protection programs at the federal, state, and local levels.[45]

While the *SDWA* has no specific provisions for the creation of groundwater protection programs that relate to livestock waste, individual state programs supported under the *SDWA* vary depending upon regional problems and features. For example, Kentucky's *Agriculture Water Quality Act* (1994) was passed to protect surface and groundwater from agricultural pollution. The act requires all land owners with 10 or more acres to develop and implement a farm water quality plan.

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[43] U.S. Environmental Protection Agency (USEPA), Office of Water. 1999c. *Safe Drinking Water Act, Section 1429: Ground water Report to Congress, Final Report* (Washington, D.C.), <gwpc.site.net/gwreport/GWRindex.htm>.
[44] Ibid.

2.3.3 Animal Feeding Operations Guidelines and Regulations

Animal Feeding Operations (AFOs) are agricultural enterprises where animals are kept and raised in confined situations. Feed is brought to the animals, rather than the animals grazing or otherwise seeking feed in pastures, fields, or rangeland. Most livestock operations fall within this broad definition. For regulatory purposes, it is useful to make distinctions between AFO types. The USEPA definition[46] considers that an AFO facility meets the following criteria:

- animals have been, are, or will be stabled, confined and fed, or maintained for a total of 45 days or more in any 12-month period and
- crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

A Concentrated Animal Feeding Operation (CAFO) is defined as an AFO facility that

- confines more than 1,000 Animal Units (AUs)[47]
- OR confines between 301 to 1,000 AUs and discharges pollutants into waters of the United States through a man-made ditch, flushing system, or similar man-made device, or directly into waters of the United States that originate outside of and pass over, across, or through the facility or otherwise come into direct contact with the animals confined in the operation.

According to the 1992 Agricultural Census, about 450,000 farm operations nationwide met the conditions for AFOs. The vast majority are small farms, with about 85% having fewer than 250 AUs.[48] About 6,600 farms had more than 1,000 AUs and are thus considered to be CAFOs by the USEPA. Between 1987 and 1992, the total number of AUs in the US increased by about 3%, or 4.5 million units. During this period, the number of AFOs decreased, indicating a consolidation within the industry overall and greater production from fewer, larger AFOs. Given industry trends, the USEPA and USDA believe that as many as 10,000 CAFOs may exist in 2000.

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[45] Ibid.
[46] Individual states may have slightly different definitions of AFOs and CAFOs, but any state-level differences would result in regulatory control that is at least as strict as the federal definition.
[47] 1,000 Animal Unit equivalents: 1,000 slaughter and feeder cattle, 700 mature dairy cattle, 2,500 swine, 30,000 laying hens or broilers (if a liquid manure system) or 100,000 laying hens or broilers if a facility uses continuous overflow watering.
[48] USGAO, 1995.

Wastes from AFOs can affect public health and water quality through direct discharge into a surface water body or through runoff, either directly from the facility or from manure applied to land. The USGAO estimates that 90% of CAFO-generated waste is applied to land.[49]

The USEPA is currently revising its guidelines for CAFOs as a result of the 1999 *USDA-USEPA Unified National Strategy for AFOs*. Existing regulations affect about 2,000 operations defined as CAFOs (having 1,000 or more AUs). New regulations will likely increase the number of farms classified as CAFOs by including restrictions for operations with unacceptable conditions and those that are found to contribute significantly to water quality impairment within a specific watershed. USEPA anticipates completing these guidelines by December 2001 for hog and poultry, and for beef and dairy operations in December 2002. The USEPA anticipates that the new regulations will increase the number of operations requiring federal permits from 5,800 to up to 20,000.[50] A major impetus for these reforms is the regulatory objective set by the *Clean Water Act*.

2.3.4 Livestock Waste Runoff and Non-point Source Pollution Policies

The Clean Water Action Plan (CWAP), released in February 1998, identified runoff as the most important remaining source of water pollution in the United States, with agricultural runoff from livestock waste listed as a specific target for future action. The action plan noted that nationwide, 130 times more animal waste than human waste is produced, or roughly 5 tons for each citizen.

The U.S. General Accounting Office reports that

> AFOs are widely recognized to pose a number of risks to water quality and public health, due to the amount of animal manure and wastewater they generate. Animal waste runoff can impair surface and groundwater by introducing pollutants, such as nutrients (including nitrogen and phosphorus), organic matter, heavy metals, sediments, pathogens (including bacteria and viruses), hormones, antibiotics, and ammonia. Excess nutrients in water can contribute to eutrophication, anoxia, and toxic algal blooms, and have been associated in the United States with outbreaks of microbes such as

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[49] Ibid.
[50] USGAO, 1999.

> *Pfiesteria piscicida*. Pathogens such as *Crytosporidium* have been linked to impairments in drinking water supplies and threats to human health. Pathogens in manure can also create a food safety concern if manure is applied directly to crops at inappropriate times. Nitrogen, in the form of nitrate, can contaminate groundwater stocks. These pollutants are transported by rainwater, snowmelt, or irrigation water through or over land surfaces and are eventually deposited in rivers, lakes, and coastal waters or introduced into groundwater. These can affect water quality and public health in several ways, such as contaminating drinking water supplies and killing fish and wildlife.[51]

Runoff from agricultural sources is a form of non-point source pollution. Non-point sources (NPS) are not subject to federal NPDES permit requirements under the *Clean Water Act*. The USEPA strategy to abate non-point sources focuses on land and runoff management practices, rather than on effluent treatment.[52] A 1987 amendment to the *CWA* created section 319, which is intended to provide a national framework to address NPS pollution. Section 319 requires states to assess NPS pollution and implement management programs. It also authorizes USEPA to issue grants to states for assistance in implementing management programs. A recently published USEPA report gives technical assistance to state program managers and others on "the best available, economically achievable means of reducing non-point source pollution of surface and groundwater from agriculture."[53] Finally, in addition to increasing funding to the USDA programs by $100 million, the CWAP doubled federal funding for the federal NPS Program to $200 million annually.

2.3.5 Regulation of Point Source Pollution from Livestock Waste

The primary device for point source pollution regulation in the United States is the National Pollutant Discharge Elimination System (NPDES), administered by the USEPA under the authority of the *Clean Water Act*. The program defines and classifies categories of point source pollution, and based on these definitions, firms may be required to apply for a permit. Depending upon the nature of the

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[51] Ibid.

[52] U.S. Environmental Protection Agency (USEPA), Office of Water, Nonpoint Source Control Branch, 2000, *National Measures to Control Non-point Source Pollution from Agriculture,* Draft Report.

[53] Ibid.

activity and the pollutant, the permits specify the circumstances under which the firm is allowed to operate. The USEPA issues NPDES permits directly, or individual states may be authorized to implement the NPDES program provided that the state NPDES program requirements are as at least as stringent as those imposed under the federal program. NPDES permits are for five years. The general public may participate in NPDES permit decisions. The procedures require that the public be notified and allowed to comment on NPDES permit applications.

The federal NPDES requirements specifically include regulation of Concentrated Animal Feeding Operations (CAFOs). CAFOs are defined as point sources for the purposes of the NPDES program; no such facility may discharge pollutants from a point source to waters of the United States without an NPDES permit, except for discharges resulting from a 25-year, 24-hour storm event.

The current USEPA policy treats only those AFOs that meet the regulatory definition of a CAFO as a point source, and thus are subject to the NPDES program.[54] About 2,000 CAFOs have been issued NPDES permits by the USEPA and individual states under section 402 of the *CWA*. These permits limit conditions under which discharges may be made from point sources and may also impose best management practices (BMPs). For example, poultry operations that remove waste from pens and stack it in areas exposed to rainfall or adjacent to a watercourse may be considered to have established a liquid manure system and therefore CAFOs are subject to the NPDES program. USEPA expects that between 15,000–20,000 CAFOs require permitting and enforcement under NPDES permits.[55]

Under authorization of USEPA, individual states may implement their own programs. The federal program targets CAFOs, but state regulations may be more stringent and include AFOs as well. State non-NPDES programs (state AFO programs) are typically more stringent than the federal NPDES program, thus many states authorized to implement the federal program choose not to. While state AFO programs vary, most regulate facilities through permitting programs that require animal waste disposal systems to be constructed to prevent the discharge of wastes to surface waters. As of 1999, more than 45,000 non-NPDES permits have been issued via state-level AFO programs.[56]

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[54] Another regulatory program that addresses AFOs is the Coastal Non-point Pollution Control Program, implemented under the authority of the *Coastal Zone Act Reauthorization Amendments* of 1990.

[55] USEPA, Wastewater Management and USDA, 1999; USGAO, 1999.

[56] USEPA, Wastewater Management and USDA, 1999.

Currently 43 states have AFO program requirements that are as stringent as the federal requirements. Their CAFO requirements are often more stringent than the federal requirements. CAFO permit conditions may also address land application of wastes. CAFO operators are typically required to apply waste at agronomic rates and to develop waste management plans. The waste management plan requirements vary by state. About 2,000 NPDES permits for CAFOs have been issued in the U.S.[57]

2.3.6 USDA-USEPA Unified National Strategy for Animal Feeding Operations (AFOs)

The 1998 Clean Water Action Plan (CWAP) recommended the development of a unified USDA-USEPA national strategy to minimize the impacts of AFOs on water quality and public health. The unified strategy was released in March 1999. At present, the USEPA, USDA, and state-level agencies are revising their guidelines to reflect its recommendations.

The USDA-USEPA *Unified National Strategy for Animal Feeding Operations* includes several guiding principles:[58]

1. To focus on AFOs that represent the greatest risks to the environment and public health.
2. To ensure that measures to protect the environment and public health complement the long-term sustainability of livestock production in the United States.
3. To establish a national goal and environmental performance expectation for all AFOs.
4. To promote, support, and provide incentives for the use of sustainable agricultural practices and systems.
5. To make appropriate use of diverse tools including voluntary, regulatory, and incentive-based approaches.
6. To focus technical and financial assistance to support AFOs in meeting national goals and performance expectations established in the Strategy.

The USDA-USEPA unified national strategy recommends a combination of voluntary and regulatory programs to serve complementary roles in helping AFO

[57] Ibid.
[58] USEPA, Wastewater Management and USDA, 1999.

operators to achieve individual business goals, protection of water quality, and public health objectives. The regulatory program focuses on permitting and enforcement priorities on high-risk operations, which are a small percentage of AFOs. For most AFOs, a variety of voluntary programs provide the technical and financial assistance to help producers meet technical standards and remain economically viable.[59]

2.3.6.1 *Voluntary programs for AFOs*

The strategy sets a national performance expectation that by 2009, all of the approximately 450,000 AFOs nationwide should develop and implement technically sound, economically feasible, and site-specific Comprehensive Nutrient Management Plans (CNMPs) to minimize impacts on water quality and public health. The CNMPs would address feed management, manure handling and storage, land application of manure, land management, record keeping, and other utilization options. The plans should address risks from pathogens and other pollutants as well as nutrients. The owner or operator is ultimately responsible for the development and implementation of CNMPs regardless of who provides technical assistance. The Natural Resources Conservation Service (NRCS) Field Office Technical Guide for any given region is the primary technical reference for the development of CNMPs for AFOs. Specific management practices would be expected to vary to reflect site-specific conditions or needs of the watershed.[60] These plans should include provisions to

- modify animal diets to reduce nutrients in manure;
- improve manure handling and storage to reduce chances of leaks or spills;
- apply manure to cropland in a manner that does not introduce an excess of nutrients and minimizes runoff; and/or
- employ alternative uses of manure such as selling it to other farmers, composting it and selling compost to homeowners, and generating power on the farm where the potential for land application is limited.[61]

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[59] Ibid.
[60] A more detailed listing and description of the various practices that livestock and poultry AFO operators may use to manage animal wastes are found in USDA publications, including the *National Handbook of Conservation Practices* (USDA/NRCS, April 26, 1999), <www.ftw.nrcs.usda.gov/nhcp_2.html>, and Natural Resources Conservation Service (NRCS) Field Office Technical Guides (derived from the handbook) at NRCS field offices in each state. The NRCS is part of the USDA.
[61] USEPA, Wastewater Management and USDA, 1999.

The primary effort of the voluntary strategy will be to assist operators in developing CNMPs. While these are not mandatory for AFOs in voluntary programs, they are strongly encouraged as the best possible means to manage potential water quality and public health impacts.

States are expected to support development of voluntary CNMPs consistent with other clean water program priorities. AFO operators are expected to be full partners in the development and implementation of CNMPs through voluntary programs. The successful implementation of voluntary programs is expected to require the support of local leadership. A key feature will be environmental education of AFO operators adhering to older BMPs, who are unintentionally contributing to runoff problems due to lack of access to new information. Financial cost-share and loan programs are recommended to provide AFO operators with incentives to participate in voluntary programs. Many states have financial assistance programs that supplement Federal assistance.[62]

AFO owners/operators are encouraged to participate in other state and federal programs to improve water quality and implement runoff abatement activities, including state cost-share programs and the USEPA's National Agriculture Compliance Assistance program authorized under the *Clean Water Act*. All USDA, USEPA, federal, state, and local programs are expected to be used together as tools to leverage resources to help AFO owners to voluntarily address water quality and public health impacts.

2.3.7 Federal Financial Assistance for Animal Waste Management

The USDA administers the major federal programs that deliver financial and technical support to producers to manage animal wastes. Most assistance is provided through the USDA's Environmental Quality Incentives Program (EQIP), established by the 1996 Farm Bill to provide a voluntary conservation program for farmers and ranchers. Half the funds must be directed toward livestock-related concerns. Cost-sharing may pay up to 75% of the costs for certain practices. Incentive payments may be made to encourage producers to adopt nutrient and manure management practices. Funding priorities are based on the importance of the environmental problem addressed and the ability to address the problem with the available funds, with the goal of maximizing the environmental benefits for each EQIP dollar spent.[63]

[62] Ibid; USGAO, 1999.
[63] USGAO, 1999.

The EQIP program shares costs of implementing waste management strategies with farmers through direct payments. Additional programs are administered by the USEPA or the Fish and Wildlife Service of the Department of Interior. Producers generally learn about programs and assistance through local officials, who help them select waste management practices and apply for financial assistance. For fiscal years 1996 through 1998, federal agencies provided $384.7 million plus technical assistance to producers; they estimated they would provide about $114 million in fiscal year 1999. USDA provides about 85% of the available financial assistance, while the USEPA provides about 10% and the Fish and Wildlife Service provides most of the remaining 5%. Table 2-2 shows the breakdown of funding for animal waste management by program. Individual animal waste management practices supported by the USDA EQIP program and the costs of implementing them are summarized in table 2-3.

The Conservation Reserve Program (CRP) was authorized by the 1985 Farm Bill. It is a voluntary program that offers annual rental payments, incentive payments, and cost-share assistance for long-term cover-crops on highly erodible land. Land is accepted into the CRP through a competitive bidding process where all offers are ranked using an environmental benefits index.[64]

Federal expenditures for animal waste management research in the United States is largely funnelled through the USDA's Agricultural Research Service (ARS) and Cooperative State Research, Education and Extension Service (CSREES). The ARS research is done primarily through its National Program for Manure and By-Product Utilization, which has focused on non-structural practices such as alternative feeds and land-based manure management practices. Between 1996 and 1998, ARS spent $13.5 million for research related to animal waste management, and estimates that $9.1 million was spent in 1999. The growth in funding allocations is a result of public concern about environmental and health issues. CSREES provides funds to state agricultural experiment stations, universities, and other institutions. Nearly 400 projects in 1997, costing about $6.9 million, were related in part to animal waste management. Research included combining aerobic and anaerobic methods to treat wastes, and combustion of poultry litter for electricity generation. Estimates for 1998–1999 costs are not available. Individual states and private organizations also fund research on animal waste management practices.[65]

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[64] Ibid.
[65] Ibid.

Table 2-2 U.S. Programs Providing Financial and Technical Assistance for Animal Waste Management

Program	Program Description	Amount Provided FY 1996–98 ($ million US)	Amount Estimated FY 1999 ($ million US)
USEPA Programs			
National Non-point Source Program	Provides grants to states to (1) assess the extent to which non-point sources cause water quality problems and (2) develop management programs to address these problems. Several states have used these USEPA grants to assist livestock and poultry producers install animal waste management practices.	17.6	Not available [a]
Clean Water State Revolving Fund	Provides capitalization grants to states, which must provide a matching amount equal to 20% of the total grant and agree to use the money first to ensure that wastewater treatment facilities are in compliance with the deadlines, goals, and requirements of the *Clean Water Act*. All states have met their priority wastewater infrastructure needs, and some have begun using this revolving fund to support programs to deal with non-point source pollution, including animal waste runoff. Some states use this funding to make low-interest loans to producers for implementing animal waste management practices.	20.3 [b]	Not available [a]
AgSTAR	Provides technical assistance to producers interested in installing waste management systems, such as covered lagoons and anaerobic digesters that reduce odours and recover methane gas for use as an on-farm power source.The program has established several projects on farms in at least five states.	1.9	0.4
USDA Programs			
Environmental Quality Incentives Program (EQIP)	Provides financial and technical assistance to producers who agree to enter 5- to 10- year contracts to implement conservation practices. Generally shares up to 75% of the costs to install practices, with a maximum of $10,000 for any fiscal year, or $50,000 for any multiyear contract. Program also provides incentive payments for nutrient management initiatives. Focuses on priority areas such as watersheds with environmental concerns. At least 50% of EQIP funding is reserved to assist livestock and poultry producers; these producers must have fewer than 1,000 animal unit equivalents.	208.9	87.0

[a] These program funds are distributed by state and local governments according to local priority needs. As a result, USEPA is unable to estimate the portion of these funds that will be used to assist producers in managing their animal wastes.

[b] States have only reported to USEPA the aggregate amount of loans made for animal agricultural runoff since they began using these funds for non-point source pollution-related activities. Hence, some states may have been providing loans for this purpose since 1988. However, USEPA officials said that most states began using these funds for non-point source projects in the mid-1990s.

Table 2-2 U.S. Programs Providing Financial and Technical Assistance for Animal Waste Management, cont'd.

Program	Program Description	Amount Provided FY 1996–98 ($ million US)	Amount Estimated FY 1999 ($ million US)
USDA Programs (continued)			
Small Watershed Program	Provides financial and technical assistance through state and local agencies to producers who usually enter 5- to 10- year contracts to implement management practices. Generally shares from 50 to 75% of the actual costs associated with installing management practices, with a maximum of $100,000 per participant for the life of the program. Focuses on watersheds smaller than 250,000 acres.	49.6	17.9
Agricultural Conservation Program	A terminated program that provided financial and technical assistance to producers who entered multiyear contracts to install conservation practices. Generally shared up to 50% of the costs to implement practices, with a maximum of $3,500 annually and $35,00 for a 10-year contract. USDA is still making payments under some of these contracts.	62.0	Not available
Conservation Reserve Progam	Provides land rental payments, for 10 to 15 years, to producers who agree to convert highly erodible or other environmentally sensitive land to approved vegetated cover (such as grasses or trees). Program also offers cost-share assistance to establish vegetated cover and fencing on enrolled land.	5.9	Not available
Farm ownership loans	Provides direct loans of up to $200,000, or guaranteed loans of up to $300,000 for up to 40 years to, among other things, purchase land, construct buildings or make other structural improvements, and develop farmland to promote soil and water conservation.	[c]	[c]
Farm operating loans	Provides direct loans of up to $200,000, or guaranteed loans of up to $400,000 for up to 7 years to, among other things, purchase livestock, poultry, equipment, feed, and other farm supplies; develop and implement soil and water conservation practices; and refinance debt.	[c]	[c]
Fish and Wildlife Service, Department of the Interior			
Partners for Fish and Wildlife	Provides cost-share and technical assistance to private landowners, including livestock and poultry producers, who are interested in implementing practices that improve habitat for federal trust species[d], decrease overland runoff, reduce stream degradation, and improve forage production and management. Cost-share assistance under the partners program generally requires a 50% match from the landowner. However, the program has the flexibility to share costs of more or less than 50%, on a case-by-case basis.	18.3	8.7

[c] Loans not tracked for specific soil and water conservation practices, or whether the loan recipient is an animal producer.

[d] Federal trust species include migratory birds, threatened and endangered species, anadromous fish (fish that migrate between fresh and salt waters, such as salmon), and marine mammals.

Table 2-2 U.S. Programs Providing Financial and Technical Assistance for Animal Waste Management, cont'd.

Program	Program Description	Amount Provided FY 1996–98 ($ million US)	Amount Estimated FY 1999 ($ million US)
Farm Assessment System (Farm*A*Syst)	Supports a network of 45 state programs. The program provides producers with state-specific worksheets to help them identify and assess the causes of non-point source pollution, pinpoint pollution risks on their property, and identify site-specific actions to reduce the causes of non-point source pollution, such as nitrogen and phosphorus nutrients, pesticides, and pathogens. This assessment can assist producers in developing feasible plans to prevent pollution and in locating sources of financial assistance through other programs, such as EQIP, to implement practices such as those for managing animal wastes.	0.2 [e]	0.06 [e]
TOTAL			

[e] According to Farm*A*Syst officials, no USEPA funds have been directed toward animal waste management activities, only USDA funds have been used.
Source: USGAO, 1999.

2.3.8 Best Management Practices (BMPs) Recommended in the United States

The USDA-USEPA Unified National Strategy for AFOs sets a national performance expectation: all AFO owners and operators must develop and implement technically sound and economically feasible, site-specific, comprehensive nutrient management plans (CNMPs) by 2009.[66] A CNMP identifies actions that will be implemented to meet clearly defined nutrient management goals at an agricultural operation. Components of a CNMP include feed management, manure handling and storage, land application of manure, land management, record keeping, and other options for manure use such as composting and power generation.[67]

The National Agriculture Compliance Assistance Center (NACAC) provides an outline and source material that describes the basic components of the USEPA's guidelines for recommending specific management practices to control the impact of livestock waste on water resources.[68] The USDA-USEPA unified

[66] USEPA, Wastewater Management and USDA, 1999.
[67] USGAO, 1999.
[68] This outline, plus links to additional resources on best management practices, is available online at <http://es.epa.gov/oeca/ag/sectors/animals/anafobmp.html>.

Table 2-3 Selected Practices Installed with EQIP Assistance and Average Installation Costs ($US)

Practice	Definition/purpose	Average Installation cost $US per unit
Composting	Facility for the biological stabilization of waste organic material.	$8,409/facility
Cover and green manure crop	Close-growing legumes or small grain to control erosion during periods when the major crops do not furnish adequate cover. Possesses filtering qualities.	$24.90/acre
Diversion	Channel constructed to divert excess water from one area for use or safe disposal in other areas.	$3.10/foot
Fence	Constructed barrier to livestock, wildlife, or people.	$1.54/foot
Filter strip	Area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater. May require a constructed ditch ('setting basin') between a barnyard and the vegetative strip to ensure that solids do not reach surface waters.	$4,650/acre
Grassed waterway	Natural or constructed channel that is shaped and established in vegetation to convey runoff from water concentrations without causing erosion or flooding and to improve water quality.	$2,644/acre
Manure transfer*	Conveyance system, such as pipelines and concrete-lined ditches, that transfer animal waste (manure, bedding material, spilled feed, process and wash water, and other residues associated with animal production) to (1) a storage or treatment facility, (2) a loading area, and (3) agricultural land for final utilization.	$10,932/system
Nutrient management	Managing the amount, form, placement, and timing or applications of nutrients, such as farm animal waste, for optimum crop yields while minimizing the entry of nutrients to surface water and ground water.	$17.10/acre
Roof runoff management	Gutters, downspouts, and drains for controlling roof runoff water to prevent this runoff from flowing across feedlots, barnyards, or other areas to reduce pollution and erosion; improve water quality; and prevent flooding.	$3,098/facility
Streambank and shoreline protection	Vegetation or structures used to stabilize and protect banks of streams, lakes, and estuaries to reduce sediment loads – including nutrients from animal waste – causing downstream damage and pollution.	$27.11/foot
Trough or tank	Provides drinking water for livestock, which can eliminate the need for livestock to be in streams; this, in turn, reduces the amount of livestock waste entering streams.	$905/trough or tank
Waste management system	Planned system in which all necessary components are installed for managing liquid and solid waste, including runoff from concentrated waste areas, in a manner than does not degrade air, soil, or water resources. A system may consist of a single component, such as a diversion, or of several components.	$20,477/system
Waste storage facility	Impoundment made by constructing an embankment and/or excavating a pit or dugout or by fabricating a structure to temporarily store wastes, such as manure, wastewater, and contaminated runoff.	$19,141/facility
Waste treatment lagoon*	Impoundment made by excavation or earthfill for biological treatment of animal or other agricultural waste.	$20,777/lagoon
Waste utilization	Agricultural waste applied to land in an environmentally acceptable manner while maintaining or improving soil and plant resources.	$17.10/acre

*Because fewer than 30 of these systems or facilities have been completed under EQIP, the average cost may not reflect a statistically valid estimate.

Source: USGAO, 1999.

national strategy is currently developing guidance and assessment tools, numerical criteria, software, and other support for regions to develop their management measures. The USEPA will assist states in adopting the criteria into their water quality standards by 2003.

The strategy does not prescribe specific best management practices, but rather specifies "management measures," defined as "economically achievable measures to control the addition of pollutants to our coastal waters, which reflect the greatest degree of pollutant reduction achievable through application of the best available non-point pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives."[69] Individual states are expected to specify the particular practices and technologies that achieve pollution control measures, appropriate for the site conditions, climate, geography, type of operations, and other features that are particular to the region. Thus, management measures are broad goals, and the individual regions are expected to determine what practices are most appropriate given specific features of their areas.

The principle is to avoid defining particular management practices as BMPs, because 'best' is a potentially subjective term, depending upon individual goals, and is highly site-specific. Even within regions, a management practice that may be considered 'best' in one area may be inappropriate in another, depending upon priorities, goals, and site-specific and watershed-specific features.

> Management practices may be structural (waste treatment lagoons) or managerial (nutrient management). Management practices generally do not stand alone in solving water problems, but are used in combinations to build management practice systems. Each practice should be selected, designed, implemented, and maintained in accordance with site-specific considerations to ensure that the practices function together to achieve overall management goals.[70]

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[69] U.S. National Agriculture Compliance Assistance Center (NACAC), 2000, *Best Management Practices (Animals)*, <http://es.epa.gov/oeca/ag/sectors/animals/anafobmp.html>.
[70] USGAO, 1999.

The emphasis is to develop coordinated groups of affordable management practices that can be used together as a system to achieve comprehensive goals at specific sites, without recommending any particular practice outside the context of an overall goal. A group of practices is termed a "management measure." USGAO[71] suggests that the factors that should influence the choice of management practices for a management measure include:

- site-specific factors, type and volume of waste, and proximity to surface or groundwater;
- cost considerations; and
- state and local regulations.

Recommended components of management measures for AFOs include:

- *Divert clean water:* Siting or management practices should divert clean water (run-on from uplands, water from roofs) from contact with holding pens, animal manure, or manure storage systems.

- *Prevent seepage:* Buildings, collection systems, conveyance systems, and storage facilities should be designed and maintained to prevent seepage to ground and surface water.

- *Provide adequate storage:* Liquid manure storage systems should be (a) designed to safely store the quantity and contents of animal manure and wastewater produced, contaminated runoff from the facility, and rainfall from the 25-year, 24-hour storm, and (b) consistent with planned use and schedules. Dry manure should be stored in production buildings or storage facilities, or otherwise covered to prevent precipitation from coming into direct contact with the manure.

- *Application:* Apply manure in accordance with a nutrient management plan that meets the performance expectations of the management measure.

- *Address lands receiving wastes:* Areas receiving manure should be managed in accordance with the erosion and sediment control, irrigation, and grazing management measures as applicable, including practices such as crop and grazing management practices to minimize movement of applied materials, and buffers or other practices to trap, store, and 'process' materials that might move during precipitation events.

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[71] Ibid.

- *Record keeping:* AFO operators should keep records that indicate the quantity of manure produced and its use or disposal method, including land application.

- *Consider the full range of environmental constraints and requirements:* When siting new facilities or expanding existing ones, operators should consider the proximity to surface waters, areas of high leaching potential, and sink holes or other sensitive areas.

The same study compared practices used in other countries with those in the United States and found general similarities.[72] Most practices are based on the eventual application of waste to agricultural land as a fertilizer or soil conditioner. Reviewed waste management practices functioned to

- limit runoff by cementing and curbing animal confinement areas or planting grassed buffers around these areas;

- collect and store waste, e.g., with scraping or flushing systems, storage tanks, or retention ponds;

- alter or treat waste, e.g., by reformulating feed mixes or composting;

- use waste, e.g., as an organic fertilizer, as an additive to animal feed, or for on-farm energy generation, using methane produced from anaerobic decomposition of wastes in covered lagoons or tanks.[73]

The study noted some differences in approach and emphasis between countries that relate to differences in political and economic circumstances. The use of anaerobic digesters to produce methane for on-farm energy generation is more prevalent in Europe than in the United States. Germany alone has approximately 400 digesters, compared with 28 on U.S. farms. USEPA, USDA, and Dept. of Energy officials indicate that the relatively low cost of energy in the United States as compared to Europe make these options less attractive to U.S. farmers.

Some European countries, such as Denmark, Germany, and the Netherlands, have quasi-government or commercial companies that operate centralized plants that accept organic waste material for anaerobic digestion. These plants produce

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[72] Ibid.
[73] Ibid.

and market the by-products of digestion, including methane gas, nutrient-rich fertilizers, and compost. The plants collect user fees from farms, firms, and municipalities that supply the waste. Some receive government subsidies to cover operating expenses. By 1997, about 40 such plants in Europe received animal wastes, compared with only two plants in the United States. The discrepancy is due in large part to the relative differences in energy prices, costs of regulatory compliance, and the amount of available land for application of organic wastes.[74]

Animal waste is used for commercial energy production in some European countries. These plants require government subsidies to remain competitive with plants that use fossil fuels.[75]

Some countries have imposed specific nutrient management regulations. Denmark, Japan, the Netherlands, Sweden, and the UK regulate and limit application of animal wastes to agricultural lands. Denmark requires that farmers meet specific cropland acreage-to-animal ratios.

USEPA officials have investigated municipal sewage treatment technologies for the treatment of wastewater and sewage from large dairy and hog operations. They concluded that the technologies would require significant modifications to handle the more concentrated wastes from farm operations. Also, the capital investment and operating and maintenance costs would be very high. The construction of such on-farm treatment plants may require financial assistance, as is often the case for municipal facilities. Producers may have access to specialized funds and loans through the *Clean Water Act*. The USEPA notes that municipal sewage systems with excess capacity may handle animal wastes, such as one facility in southern California that accepts animal wastes from a nearby dairy farm. Such treatment processes still result in a residual sludge that must either be landfilled, incinerated, or applied to agricultural lands.[76]

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[74] Ibid.
[75] Ibid.
[76] Ibid.

2.3.9 State-level Regulations for Non-point Source Pollution[77]

A study prepared for the USEPA by the Environmental Law Institute examined the laws of all 50 states to identify and analyze enforceable mechanisms for the control of non-point source water pollution.[78] The study highlighted the great diversity in legislation among states. The study also emphasized that it is not possible to assess the effectiveness of enforceable mechanisms to deal with specific problems in a state outside the context of the state's entire program. Agriculture was noted as the most problematic area for enforceable mechanisms, in part because many laws and regulations include exemptions for agriculture. State laws regarding water pollution from agriculture often rely on incentives, cost-sharing, and voluntary programs instead of enforceable regulatory mechanisms.[79]

State laws tend to delegate standard setting, implementation, or enforcement duties to units of local government or conservation districts. About a quarter of the states authorize individual soil and water conservation districts to adopt enforceable "land-use regulations." However, most of these require approval by landowner referenda, with approval requiring a 66% to 90% majority vote. Kentucky, for instance, requires approval from at least 90% of the landowners.[80] Some examples of these are described in Section 2.4.

Agricultural nutrient regulation is typically through state CAFO regulations, similar to the federal requirements but with variations on the number of animal units or with the addition of siting requirements. Some states have adopted enforceable codes of accepted agricultural practices or nutrient regulations. Some provisions allow districts to order abatement of agricultural pollution. Several of these laws provide that abatement cannot be ordered unless state or federal cost-share money is provided to help pay for the required action.[81]

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[77] Another source that discusses state-level regulations is W.R. Lowry, 1992, *The Dimensions of Federalism: State Governments and Pollution Control Policies* (Durham, NC: Duke University Press).
[78] Environmental Law Institute (ELI), 1997, *Enforceable State Mechanisms for the Control of Nonpoint Source Water Pollution* (Washington, D.C.), <www.epa.gov/OWOW/NPS/elistudy/index.html>.
[79] Ibid.
[80] Ibid.
[81] Ibid.

Many states have mechanisms to make BMPs, if not enforceable, at least more than voluntary by linking them to other enforcement mechanisms. The study identified five approaches currently in use by various states:

- make BMPs directly enforceable in connection with required permits and planning approval;
- make BMPs enforceable after the fact, when a "bad actor" is causing pollution;
- make BMPs the basis for an exemption from a regulatory program;
- make compliance with BMPs a defence to a regulatory violation; and
- make compliance with BMPs a defence to nuisance actions.

The study noted that the most sophisticated state regulations appear to be arising on a targeted watershed basis. For example, Wisconsin integrates soil and water conservation districts into the planning, administration, and enforcement scheme.

2.3.10 State Livestock Waste Management Regulations in Kentucky

The USEPA's State Compendium *Programs and Regulatory Activities Related to Animal Feeding Operations* provides details about individual state regulations that are in addition to the federal USEPA requirements. This subsection, featuring Kentucky and New York, is largely based on the Compendium and on information provided by the Kentucky Department for Environmental Protection Web site.[82]

The state of Kentucky issues Kentucky No Discharge Operational Permits to AFOs, with more than 1,200 being issued to beef, dairy, and swine operations by 1999. In 1998, Kentucky imposed a moratorium on the expansion of hog AFOs until state management and regulatory plans could be developed. *Regulation 401* KAR 5:009 (permits for swine-feeding operations) went into effect in November 1998, but was later found to be too restrictive. It was to be replaced during 2000.

As of 1999, about 50 livestock facilities in Kentucky met or exceeded the USEPA CAFO definition and therefore required NPDES program permits. In addition,

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[82] Kentucky Department for Environmental Protection (KDEP), 2000, *An Overview of Kentucky's Waters* [online], [cited February 12, 2002], <www.water.nr.state.ky.us/dow/dwover.htm>.

a state-level non-NPDES individual permit is required of CAFOs. Permit conditions cover effluent, management, and land application of wastes. Land application permits cover both agronomic rates and offsite disposal.

The Kentucky Department of Environmental Protection, Division of Water, administers Kentucky's NPDES program under authority of the USEPA. The Division of Water is also responsible for issuing waste permits and administers the voluntary non-point source pollution grant program. The NPDES program issues permits and is administered through the Kentucky Division of Water's Discharge Elimination System. In addition to the NPDES permits, the Division of Water issues two types of state permits that directly affect AFOs:

- *Wastewater Facility Construction Permits* are required prior to beginning construction or modification of any sewage system used for treatment of wastewater. This permit requires detailed plans that describe discharge points and highlight new construction features. An engineering report must be submitted before construction is authorized. After construction, the applicant must submit certification by a registered engineer that the facility was constructed according to the approved plans.

- *Swine Waste Management Permits*, part of the emergency swine-feeding operations regulation, is required of all new swine-feeding operations with over 1,000 animals, and of any existing operations that increase capacity. The regulations include construction and operational requirements for swine waste lagoons and the land applications of waste from the lagoons. The regulations also provide siting regulations for waste lagoons, restrictions on land applications, and monitoring and testing requirements. Each operation must develop a waste management plan that describes the crop nutrient requirements, how waste will benefit the surrounding land, and when and where it will be applied. A monitoring plan requires the permittee to conduct groundwater monitoring and maintain records for 10 years.

A barn or waste lagoon cannot be located in a 100-year floodplain or a jurisdictional wetland, nor within 150 feet of a lake or river. Land application of livestock waste is not allowed within 150 feet of water wells. Waste management system operators who intend to apply liquid hog manure must take soil samples from the fields to be treated and complete an analysis of swine waste nutrient content. Land application is not allowed on saturated ground, during precipitation, or on frozen ground, and waste must not be applied at a rate that exceeds infiltration. All swine waste application areas must have a filter strip on its lowest side.

Kentucky prohibits the discharge of any pollutant or substance that shall cause or contribute to water pollution "in contravention of any rule, regulation, permit, or order" (Ky. Rev. St. 224.70-110). The law provides that if a violation is traceable to an agricultural operation, it is handled under the state's enforceable Agriculture Water Quality Act, rather than under the stricter water pollution control act (Ky. Rev. St. 224.120(10)).[83]

The *Agriculture Water Quality Act* (1994) was passed to protect surface and groundwater from agricultural pollution. The act requires all landowners with 10 or more acres to develop and implement a farm water quality plan based on guidance from a Statewide Water Quality Plan (Ky. Rev. Stat. 224.71-100 to 71–145). Some technical and financial assistance is available during development. Section 319 Non-point Source Implementation Grants, under the *CWA*, can cover up to 60% of the total cost of voluntary pollution control projects.

Landowners must use BMPs for their plans under the Statewide Water Quality Plan and implement those BMPs within five years. Kentucky establishes that a person engaged in an agricultural operation in a water quality priority protection region where pollution has been documented "shall be presumed in compliance" if BMPs have been implemented as required by plan (Ky. Rev. Stat. 224.71-120(9)). Conducting an agricultural operation in violation of the plan in a manner that results in water pollution is a violation of law; failure to comply after receipt of written notice and provision of technical assistance and financial assistance "when possible" renders a person a "bad actor" subject to a civil penalty not to exceed $1,000 (Ky. Rev. Stat. 224.71-130).

Kentucky is part of USEPA Region 4 with includes Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee. Region 4 is developing a regional strategy to include objectives of the U.S. Clean Water Action Plan and the USEPA/USDA Unified Strategy for AFOs.

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[83] U.S. Environmental Protection Agency (USEPA), Office of Wastewater Management, 1999, *State Compendium: Programs and Regulatory Activities Related to Animal Feeding Operations*, August, 1999, <www.epa.gov/owm/stcpfin.pdf>.

2.3.11 State Livestock Waste Management Regulations in New York

The following information about New York State was collated as part of the USEPA's *State Compendium: Programs and Regulatory Activities Related to AFOs.*[84]

As of 1999, there were approximately 150 large CAFOs (over 1,000 AUs) and 850 medium CAFOs (between 300 to 999 AUs) in New York. No state level non-NPDES approval is required for construction and operation of an AFO. A general NPDES permit is required for those operations that fall under USEPA regulations, and the permit conditions cover waste management. The USEPA Region that includes New York is currently drafting a regional level AFO program.

Historically, New York did not issue state-level pollutant discharge permits for CAFOs. This policy was based upon the belief that effluent guidelines could be achieved without permits through voluntary programs, augmented by enforcement of existing laws and nuisance laws in severe cases. By 1996, after a federal court decision regarding a New York CAFO, and in part due to the changing nature of dairy production toward fewer but larger farms, the New York Department of Environmental Conservation (NYSDEC) formed the CAFO Working Group. The premise of the group was that the non-regulatory approach may no longer be viable. Its role was to examine the legal, regulatory, policy, environmental, and economic issues to be considered in developing a more comprehensive approach for CAFOs.[85]

Based on options brought forward by the CAFO Working Group, NYSDEC focused on developing a general State Pollutant Discharge Elimination System (SPDES) permit for CAFOs of over 1,000 animal units and for AFOs of between 300 and 999 AUs that discharge through a man-made conveyance. These size categories correspond to the existing USEPA regulations. AFOs not covered under the state permit program would be encouraged to participate in the voluntary Agricultural Environmental Management (AEM) program,

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[84] USEPA, Wastewater Management 1999.

[85] New York State Soil and Water Conservation Committee and New York State Department of Agriculture and Markets, 2000, *Guide to Agricultural Environmental Management in New York State.* Specific details about the SPDES permit programs, and access to publications are available through an associated Web site: <www.dec.state.ny.us/website/dow/cafohome.html>.

administered by the New York State Department of Agriculture and Markets. Voluntary programs are detailed in the New York *Guide to Agricultural Environmental Management in New York State.* New York Farm Service Agencies, including the New York State Soil and Water Conservation Committee, the County Soil and Water Conservation Districts, and Cornell Cooperative Extension, are responsible for delivering many of the programs related to CAFOs.

The SPDES permit holders must develop and implement an Agricultural Waste Management Plan (AWMP). CAFOs must develop their plan within 18 months after the date of coverage and must implement the plan within 60 months of coverage. Medium-sized CAFOs must develop the AWMP within 24 months of the coverage date, and fully implement it within 60 months. The AWMP must be developed or reviewed by a qualified Agricultural Environmental Management Planner (AEMP), who must certify that the plan has been developed in accordance with Natural Resources Conservation Service guidelines. The New York State Department of Agriculture and Markets trains and qualifies Agricultural Environmental Management Planners.

The New York City Memorandum of Agreement includes the Watershed Agriculture Program (WAP),[86] intended to improve environmental practices among watershed farmers. WAP is voluntary, a substitute for regulations, and is required by the USEPA to avoid filtration orders for New York City's water supply. The goal of WAP is to develop and implement comprehensive farm management plans for each farm in the watershed. Because dairy farms are the most common, phosphorus and pathogens are the pollutants of concern. WAP suggests common BMPs, including stormwater management and improved manure storage. The required goal of WAP is to document a farmer participation rate of over 95%. As well, an ongoing monitoring program has been established to determine BMP effectiveness.[87]

A review of the New York City Watershed Memorandum of Agreement recommended that lands within the watershed that are enroled in the USDA Conservation Reserve Program (CRP) be prioritized based on frequency of flooding, vegetation type, and whether the landowner will voluntarily exclude livestock from riparian zones. It also recommended that where prioritization was not possible, rental and cost-share incentives offered by the CRP be increased

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[86] U.S. NRC, 1999.
[87] Ibid.

to retire frequently flooded farmland into riparian forest buffers and to exclude livestock from streams.[88]

New York prohibits the direct or indirect discharge of any substance that "shall cause or contribute to" a condition in violation of water quality standards (NY Env. Cons. L. 17-0501). New York state law exempts agricultural activities only from nuisance actions, and subjects the exemption to various exceptions such as increased activities and activities causing conditions dangerous to life or health (NY Pub. Health L. 1300-c).[89]

New York law requires "every owner or occupier of agricultural land" (defined as 25 or more acres and certain smaller concentrated operations) to apply to the local soil and water conservation district for a "soil and water conservation plan for the land" and requires such districts to prepare such plans (NY Soil and Water Cons. Dist. L. 9(7-a)). These requirements are enforceable; however, the law does not make the implementation of the required plan enforceable.[90]

2.4 Regulations and Policies in Europe

Concerns in the European Union (EU) about the effects of livestock waste disposal have lead to regulations that require producers either to use costly waste management techniques or to scale back production. In 1991, the EU *Nitrate Directive* was enacted as the central water quality regulatory act that applies to all member countries. This act sets a nitrate concentration of 50 parts per million (ppm) in surface water, and requires that land applications of manure not result in an excess (after plant intake) of more than 170 kg of residual nitrogen per hectare per year. Regions in the EU that do not meet these standards are declared "vulnerable" and are therefore subject to more stringent policies as necessary to bring about compliance. The newer policies targeted to vulnerable regions limit livestock production and expansions for export markets.[91]

Denmark requires farmers either to meet a given manure-to-land ratio for their own holdings, or to document that they have spread the excess manure on neighbouring lands that are in deficit. Both Danish and Dutch farmers must register their nutrient balance sheets and maintain fertilizer management plans

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[88] Ibid.
[89] ELI, 1997.
[90] Ibid.
[91] Beghin and Metcalf, 2000.

with the government. They face fines if they produce surplus nitrogen. No operations larger than 15,000 hogs are permitted. Hog farmers are required to obtain permits and construct hog manure storage facilities that have the capacity to hold one year of accumulated waste.[92]

Some of the most severe problems and most drastic regulatory measures have been felt in the Netherlands. With 15.5 million people, the country is among the most densely populated in the world.[93] Livestock agriculture is an important Dutch industry and remains an important contributor to Dutch exports. Many regions have manure surpluses, which occur when more manure is produced in the region than there is the land capacity to absorb it without exceeding environmental standards. The options left to producers are to alter livestock diets to reduce environmental impacts, transport manure to other regions of the Netherlands, process manure, or export it elsewhere in the EU. In a letter to parliament, the Minister of Agriculture, Nature Management and Fisheries, L.J. Brinkhorst, describes the "manure problem" as one of great significance to society that has been crying out for years for a solution.[94]

Manure Production Rights (MPRs) are used to regulate phosphate levels in the Netherlands. A farm's holdings of MPRs cap the number of animal units and thus its phosphate levels. MPRs may be sold and bought according to market prices, although MPR trading is restricted among livestock sectors. Each transaction is registered, and the government imposes a 'fee' in the form of 25% of the MPRs that are exchanged in each transaction. Farms can trade MPRs within regions. Between-region trades can occur as long as the MPRs flow from regions with manure surpluses to those with manure deficits.[95]

MPRs were initially distributed among farms based on their 1987 production levels and available land holdings. In 1995, the Dutch government issued an across-the-board reduction in MPRs by 30% for hog farms, and reduced them for all livestock herds by 10% in 1998–1999. A minimum 20% further decrease

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[92] Ibid.

[93] The Netherlands, Ministry of Agriculture, Nature Management and Fisheries, 2001, "Policy theme: The environment" [online], [cited August 10, 2001], <www.minlnv.nl/international/policy/environ/>.

[94] L.J.Brinkhorst and J.P. Pronk, 1999, "*Integrated Approach to Manure Problem*," Letter to the Dutch Parliament, 10 September 1999, <www.minlnv.nl/international/info/parliament/03.htm>.

[95] Beghin and Metcalf, 2000.

[96] G. Fox and J. Kidon, 2000, [unpublished manuscript].

was planned by 2000, but controversial judicial cases have resulted in limits to these reductions. However, without the planned reductions in MPRs, the goal to achieve a balanced manure market by 2002 cannot be met. A balanced market would have MPR levels that correspond with the available land base, meaning no net surplus in manure production. The inability to meet the target is problematic, since the European Commission had found that the country was in violation of EU nitrogen targets.

In September 1999, the Dutch government approved a proposal for a new manure policy, to be phased in for all livestock farms to bring Dutch farmers into compliance with EU directives. Farmers must dispose of livestock waste according to set maximum animal manure deposits of 170 kg nitrogen per hectare per year for arable land, 210 kg nitrogen for fodder crops and 300 kg per year for grassland. Farmers in surplus would be fined according to a levy of Dfl 20 per kg of phosphate and Dfl 5 per kg of nitrogen. Fines have been increased to reduce the incidences of surpluses. Individual farmers would be required to enter into contracts with other landowners to prove that they can deposit their manure according to these standards. Farmers unable to produce such contracts would be in violation of the law and could apply for financial assistance to cease operations. This system will be phased in so the new system of manure contracts would only be fully operational by 2005. At that time, the MNRs, pig production rights, and poultry production rights would expire.

The new policy does not differentiate between livestock sectors; it would apply to all livestock farmers. The proposals are expected to reduce livestock numbers by 25–30% for pigs, 15–20% for poultry, 25–30% on finishing farms, and 10% for veal calves. The policy would have a drastic impact on farm income. For this reason, the Dutch government recognizes that social and economic support programs should accompany the restructuring of the livestock sector.

2.5 Regulations and Policies in Canada

Approaches to water quality protection from livestock agriculture in New Brunswick and Quebec are summarized. Although both approaches have been designed relatively recently to deal specifically with increasingly concentrated livestock facilities, they are quite different.

2.5.1 New Brunswick

New Brunswick's approach combines voluntary mechanisms provided by manure management guidelines that were revised in 1997 plus regulatory mechanisms under the authority of the province's *Clean Water Act* and *Health Act*.[96] The New Brunswick *Health Act* prevents locating livestock facilities less than 90 m from a waterway or dwelling, on marshy or swampy land, or in a flood plain.

The *Watercourse Setback Act* (under the *Clean Water Act*) allows municipalities to designate as protected areas those watersheds that serve as municipal water supplies. Land uses in designated protected areas are subject to regulatory restrictions beyond the normal provincial environmental and health provisions. For example, the setback restricts establishment of any new agricultural land use within 75 m of a watercourse, and allows no agricultural activity, including grazing livestock, within 30 m. Tillage must be managed to prevent surface runoff from entering the watercourse. Up to 80% of the costs of materials and foregone income within the 30 m are available from a joint federal-provincial subsidy. As of 1999, 31 watersheds were designated as protected areas in New Brunswick.[97]

The province's new manure management guidelines, approved in 1997, replaced the 1983 *Guidelines for Livestock Manure and Waste Management in New Brunswick*.[98] The guidelines provide recommended practices and are not regulations. They do not supersede land-use acts and regulations such as New Brunswick's *Clean Environment Act*, the *Clean Water Act*, the *Health Act*, and the *Agricultural Land Protection and Development Act*.

The guidelines aim to reduce odour and water contamination from livestock operations. The use of manure as valuable fertilizer is emphasized through adoption of management practices that promote removal of nutrients by cultivated crops. The recommended minimum separation distances are in part based on hydrogeological information such as groundwater sources, quality, and quantity; depth to the water table; depth to bedrock; and surface slope.

Manure storage facilities must be designed to avoid contamination of the ground, and contaminated surface water must be prevented from leaving the property. Non-earthen manure storage structures (concrete and glass-lined

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[97] Ibid.

[98] New Brunswick, Department of Agriculture, Fisheries and Aquaculture, Land Development Branch, 1997, *Manure Management Guidelines for New Brunswick* (Fredericton, NB), <www.gnb.ca/afa-apa/20/10/2010005e.htm>.

metal manure storage structures) are to be constructed according to the latest editions of the *National Building Code of Canada* and the *National Farm Building Code of Canada*. The design and construction of less-costly earthen structures must minimize potential pollution of surface and groundwater. The guidelines provide a set of recommendations for earthen structure construction.

The guidelines provide recommendations for the design and construction of solid manure storages, including minimum capacities of 210 days of manure accumulation or a greater volume as required to assure that the operator can spread manure on land at optimal times for maximum nutrient uptake by crops. The guidelines provide recommendations on the spreading of manure to optimize crop performance while minimizing water contamination. Requirements for a minimum land-base and application rates are supplied in tabular form. There are recommendations that land suitable for spreading manure should be either owned by the operator or under formal contractual arrangements with neighbouring landowners.

The New Brunswick *Clean Water Act* requires that manure should not be spread within 75 m of a private well or drinking water supply, other than that of the owner. The *Motor Vehicle Act* legislates that transportation and application of manure must be carried out so asto prevent spillage on public properties.

2.5.2 Quebec

Quebec enacted its regulations to reduce pollution from agricultural sources in July 1997. The goal is to minimize environmental impacts of animal agriculture by providing for leak-proof storage of livestock waste and regulating spreading activities on cultivated land.[99]

The regulation is a command-and-control style. It requires farmers to maintain an agro-environmental fertilization plan and document all manure spreading. Livestock waste spreading is restricted to growing periods before October 1 and after March 1, and the use of sprinklers and liquid manure cannons was prohibited after October 1998.

At no time is animal waste accumulating in a livestock raising facility allowed to come into contact with the soil. Animal waste storage facilities must be leak-proof, and the floor must be above the highest level of the water table. Storage

[99] Quebec, Environment Quebec, Reduction of Pollution from Agricultural Sources, Regulation Highlights, [online], [cited July 5, 2001] <www.menv.gouv.qc.ca/sol/agricole-en/>.

facilities must be situated so as to prevent infiltration by runoff. Certain solid manure storage facilities are exempt from leak-proof requirements. These facilities can only be used where there are smaller livestock populations than the limits provided by the regulation. Storage facility capacity must allow accumulated waste for a minimum period of 250 days, and 200 days for facilities built before 1997. The maximum amount of waste material that can be stored cannot exceed a facility's limit or the quantity that can be spread on the land at the facility's disposal. Surplus waste must be transported in a closed watertight container to a manure management organization.

The regulation specifies conditions under which solid manure coming from a building is exempt from watertight storage requirements. These include a minimum distance of 300 m from groundwater sources or municipal water supplies; 150 m from a lake, watercourse, natural marsh, swamp or pond; and 30 m from a ditch. In addition, such facilities must be secure from runoff infiltration, on a slope of less than 5%, not located in the 20-year floodplain of a watercourse or lake, and not located on the same site for two consecutive years. A waterproof covering must cover manure from a group of facilities comprising 35 or more animal units.

The goal of the agro-environmental fertilization plans is to ensure that livestock wastes are spread in such a manner as to minimize water pollution. The plans, which are mandatory, limit spreading by parcel. They must be prepared and signed by an agrologist who is a member of the Ordre des agronomes du Québec, a professional technologist who is a member of the Ordre des technologies professionnels du Québec, or an owner or shareholder in the operation who has completed an authorized training course. Copies of plans must be retained for two years after the activities it documents have been completed. Spreading registers must be maintained, using a downloadable template. All receipts and shipments of livestock wastes between facilities must be registered.

Owners of livestock facilities have four options for managing livestock waste: it can be spread on lands belonging to the owner or neighbouring farmers, it can be sent to a manure management organization, it can be treated by an authorized establishment, or it can be sent to a storage facility for later spreading or treatment. The regulation requires that owners and operators enter into and honour written agreements with those individuals who undertake to use the livestock waste that cannot be spread on the owners' own lands. All changes must be filed with the Minister of Environment, and all parties must retain copies of the agreements for at least two years.

Failure to comply with the regulation is subject to fines that depend upon the nature of the offence, the number of repeat offences and the legal nature of the offender, as shown in table 2-4.

2.5.3 Ontario

Ontario has not yet seen the specialized regulations and targeted guidelines for manure management practices and water quality impairment that we have documented for other jurisdictions. There are no mandatory provincial regulations that require the completion of a nutrient management plan. Instead, the province has adopted a series of eight position statements based on the best available technical expertise and designed to provide clear direction.[100] These statements include

- recommendations on nutrient management planning,
- size of agricultural operations,
- land ownership,
- distance for hauling manure,
- manure sale and transfer of ownership,

Table 2-4 Penalty Structure for Infractions of Quebec's Livestock Waste Handling Regulation

Nature of Offence	Administrative Offence	Environmental Offence
*Fines for a Natural Person**		
First offence	$1,000 to $15,000	$2,000 to $20,000
Repeat offence	$4,000 to $40,000	$5,000 to $50,000
*Fines for a Legal Person**		
First offence	$1,000 to $90,000	$2,000 to $150,000
Repeat offence	$4,000 to $120,000	$5,000 to $500,000

* The difference between a natural and a legal person could be interpreted as the difference between a person and an incorporated entity. But due to differences between Quebec law and Ontario common law, these differences may not be exactly analogous.

Source: Quebec, Environment Quebec, *Reduction of Pollution from Agricultural Sources, Regulation Highlights* [online], [cited July 5, 2001] <www.menv.gouv.qc.ca/sol/agricole.en/>.

[100] Canada, Agriculture and Agri-Food Canada (AA-FC), Ontario, Ministry of Agriculture, Food and Rural Affairs (OMAFRA), and Ontario Federation of Agriculture (OFA), 1998, *Best Management Practices, Nutrient Management Planning* (Toronto, ON: OFA).

- manure storage capacity (for which the current version recommends a capacity of 240 days),
- manure storage type, and
- minimum distances separation.

Since these statements and the associated BMPs form the backbone of the Ontario manure management policy, they will be more thoroughly reviewed following this general overview of Ontario regulations and guidelines.

During 2000, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) initiated a process for reviewing agricultural guidelines that govern the siting of concentrated livestock facilities and the expansion of existing facilities, with the view to determine whether a new policy is recommended.[101] This process includes the review of manure management practices in Ontario. A Task Force on Intensive Agricultural Operations was struck to develop options that would meet the needs of rural residents and the production and environmental needs of the agricultural sector. Consultations were held throughout Ontario. How other jurisdictions handle intensive agricultural operations was also reviewed, including other provinces, several U.S. states, and some countries in Europe. Documents associated with this process, including the discussion paper and comments, can be found at the OMAFRA Web site. This section will concern itself specifically with the existing policies of Ontario.

The 1994 *Agricultural Pollution Control Manual* outlined the codes and regulations that are most likely to apply to livestock producers in the province.[102] This document is currently under revision, since a number of the regulations and statutes have been revised since 1994. Current statutes and laws that apply to manure handling in Ontario, as originally identified in the *Agricultural Pollution Control Manual*, are updated and summarized below.

Farming and Food Production Protection Act (1998) In the words of this act, "it is in the provincial interest that in agricultural areas, agricultural uses and normal farm practices be promoted and protected in a way that balances the needs of the agricultural community with provincial health, safety, and environmental concerns." This act, administered by OMAFRA, is designed to protect farm

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[101] Ontario, Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 2001, *Discussion Paper on Intensive Agricultural Operations in Rural Ontario* [online], [cited July 2001] <www.gov.on.ca/OMAFRA/english/agops/discussion.html>.

[102] Ontario, Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 1994a, *Agricultural Pollution Control Manual* (Toronto, ON: Queen's Printer).

operations from nuisance actions. The act states that any person who carries on an agricultural operation that does not violate land-use control laws, the *Environmental Protection Act*, the *Pesticides Act*, the *Health Protection and Promotion Act*, or the *Ontario Water Resources Act* is not liable in nuisance to any person for any odour, noise, or dust from the agricultural operation as a result of normal farming practices. This act, along with the *Agricultural Code of Practice*, defines a standard of reasonable practice for resolving nuisance actions.

The Environmental Protection Act (1990) The part of this act that deals with spills is most likely to affect the agricultural community. A spill is defined as a discharge into the natural environment from or out of a structure, vehicle, or other container that is abnormal in quantity or quality in light of the circumstances of the discharge. However, the exception is that the act does not apply to animal wastes disposed of in accordance with normal farming practices. The act requires that the Ministry of Environment be notified immediately when a spill occurs, and that the owner and person who had control of the material at the time is required to contain, clean up, and dispose of the pollutant in a timely manner. Everything must be done to prevent adverse effects of the spill and to restore the natural environment.

The Ontario Water Resources Act (1990) The *Ontario Water Resources Act* is administered by the Ministry of Environment. Its purpose is to preserve the supply and purity of the natural waters. The act states that any person or municipality that discharges material of any kind, into any water body or watercourse, that impairs the quality of that water is guilty of an offence. Any discharge that is not in the normal course of events must be reported to the Minister of Environment.

The Environmental Assessment Act (1990) The purpose of the *Environmental Assessment Act* is to benefit the people of Ontario or of any part thereof by providing for the protection, conservation, and wise management of the environment. An environmental assessment, if required to be submitted for a proposed project, includes the purpose of the undertaking, the rationale for the undertaking, a consideration of alternatives, a description of environmental effects, and an evaluation of the advantages and disadvantages. The proponents pay the costs of the assessment. The Ministry of Environment reviews the assessment and the process may involve public hearings and appeals.

The Canada Fisheries Act Under the *Fisheries Act*, no person shall carry on any activity that results in the harmful alteration, disruption, or destruction of fish habitat. The Ontario Ministry of Natural Resources administers the act.

The Conservation Authorities Act (1990) This act created conservation authorities to conserve, restore, develop, and manage watersheds. Conservation authorities may purchase, lease, or expropriate land and control the flow of surface water and later watercourses.

The Drainage Act (1980) Administered by OMAFRA, this act stipulates that no person may discharge, deposit, or permit to be discharged into any drainage works any liquid material other than unpolluted drainage water. Any person who contravenes this provision is guilty of an offence with a fine of not more than $1,000.

The Planning Act (1995) This act is administered by the Ministry of Municipal Affairs to empower municipalities to create zoning bylaws to restrict the use of the land and regulate the location, type, and dimensions of buildings and structures. Water management objectives can be incorporated into municipal planning documents.[103]

Recently, some municipalities have more aggressively exercised their authority to implement bylaws and zoning in ways that target livestock facilities and nutrient management goals. For example, Oxford County adopted a nutrient management strategy in 1999. The goal of this strategy is to protect groundwater and surface water supplies in accordance with the requirements of Oxford County's Official Plan. Prior to being granted a permit for a new or expanded livestock facility on an intensive livestock farm, the operator must document that the following three elements are in place:

- a nutrient management plan,
- satisfaction of OMAFRA's Minimum Distance Separation Formula II guidelines, and
- proper containment of agricultural nutrients during storage and storage capacity for a minimum of 240 days.

Oxford County's strategy requires that permits be renewed every three years, at which times the farmer must obtain a third-party review of the nutrient management plan by OMAFRA or an agricultural consultant.

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[103] Ontario, Ministry of Environment and Energy (OMEE) and Ontario, Ministry of Natural Resources (OMNR), 1993, *Integrating Water Management Objectives into Municipal Planning Documents* (Toronto, ON: Queen's Printer).

The Ontario Building Code Act (1990) This act deals with the issuance of building permits, the powers and duties of building officials and inspectors. It is necessary to obtain a building permit for all agricultural construction projects in Ontario. Manure storages utilizing concrete, wood, or steel components fall under the definition of farm buildings and require building permits.

In addition to the acts listed above, the following codes apply.

Minimum Distance Separation Guidelines The purpose of this code is to assist farmers to reduce the potential of their livestock operations to pollute water, air, and soil. The guidelines for the "rational" use of land in relation to the livestock industry include:

- guidelines for assessing the design, location, and manure management system of new livestock buildings and the renovation or expansion of existing livestock operations;
- guidelines for evaluating the design of the manure management system on established livestock operations;
- comprehensive manure management plans for all livestock operations;
- methods to control water pollution caused by livestock watering at streams, ponds, or lakes; and
- flexibility in interpretation to cover special cases without being overly restrictive.

The MDS guidelines are intended to fill the void in the *Environmental Protection Act*. The program is voluntary unless municipalities have passed bylaws requiring permits and compliance. Permit applicants have the right to appeal to municipal committees of adjustment (which are appointed at the municipal level to hear appeals to bylaw requirements on a case-by-case basis) if the standards cannot be met. An increasing number of municipalities (such as Oxford County, described above) have developed municipal bylaws affecting livestock manure management.

2.5.3.1 *Best Management Practices in Ontario*

Best management practices (BMPs) are designed to be practical, affordable approaches to conserving soil, water, and other natural resources in rural areas. Manure management issues are covered by a variety of BMPs for soil and nutrient management, as well as livestock and poultry waste management, which consists of activities relating to the collection, transfer, storage, and land application of waste materials, plus restriction of livestock access to watercourses.

It is recognized that manure applied at excessive rates, or that leaches or runs off following applications, can damage the environment through:

- excessive growth of aquatic plants resulting from phosphorus contamination of surface water,
- contamination of water with disease-causing organisms,
- excessive nitrate levels in surface or groundwater,
- poisoning of fish and other aquatic organisms from ammonia toxicity,
- oxygen depletion of water from the addition of organic matter, and
- physical and biological damage from organic material.

BMPs have been developed for manure handling in the barn, long-term storage, and land application. There are recommendations about the transfer of manure from the barn to the storage facility. In addition to the BMPs, regulations and guidelines may apply that determine the appropriate siting and setbacks (minimum distance separation) for barns and storages. The general framework is presented in OMAFRA's *Guide to Agricultural Land Use*.[104] The advocated approach to manure management is to use the manure as a resource that can help reduce input costs for crop production and optimize crop production and quality, while protecting soil and water resources.[105]

The framework that guides nutrient management on farms stresses that farmers who practice good nutrient management can save time and money by:

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[104] Ontario, Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 1995a, *Guide to Agricultural Land Use* (Toronto, ON: Queen's Printer).
[105] Canada, AA-FC, OMAFRA, and OFA, 1998.

- purchasing and applying only what is needed;
- making better use of on-farm nutrients;
- identifying opportunities for using lower-cost alternative sources of nutrients, e.g., manure from a neighbouring farm, sewage sludge, or other forms of commercial fertilizers;
- considering more efficient fertilizer application practices; and
- using rotation, cover crops, residue management, and sound soil management practices to conserve the nutrients in the soil.

When meeting crop nutrient requirements, farmers are reminded in the BMPs that:

- final yields are not determined by fertility alone. They must also consider soil management, climate, plant population, timing, pest and weed management, and variety selection.
- some high-value crops have unique fertility requirements for quality.
- some legume crops provide some nitrogen for crops in following years, so they must include an estimate of the amount available to those crops in the overall nutrient management plan. (Legumes have bacteria in their roots which convert gaseous nitrogen into ammonium.)
- it may not be desirable to supply all of a crop's requirements from organic sources (manures, sludges, legumes, etc.) as some nutrients may be oversupplied.
- they need to know fertility levels and crop requirements in order to apply appropriate rates.
- timing is everything – if a crop can access nutrients when needed, quality and yields are higher.
- the maximum yield that can be obtained is usually not the most profitable yield.

Farmers are advised by the BMPs to test for nutrient levels and follow the recommended rates whether the testing is for soil fertility, soil pH, soil nitrate levels, plant tissue content, or nutrient content of manure or other organic wastes. The BMPs suggest that the best way to estimate the fertility of the soil is to use a reliable soil test. They point out that if too little nutrient is added the yield will suffer; if too much is added, time and money are wasted and there is a risk of polluting the environment. Nonetheless, it is pointed out that nutrients are applied to meet the crop's annual needs and to quickly raise the soil test into the range where no further additions of nutrients are required (high range). Fertilizer recommendation is constrained only for soils testing in the high range or above, so that soil test levels should not change.

Farmers should test their manure every time the manure storage area is emptied, because the quantity of nutrients and the ratio of nitrogen, phosphorus, and potassium in manure varies greatly from farm to farm, depending on the diet of the animals and the amount of bedding and liquid added to the manure.

Table 2-5 summarizes the BMPs for applying nutrients. Farmers are advised not to provide all nutrients for a crop with manure, because it is not likely that manure will release its nutrients at the right balance and time, nor is it likely that all manure has the correct composition to meet crop requirements.

For nitrogen, the amount of nitrate-nitrogen present in the soil at planting or side-dress time can indicate a soil's capacity to supply nitrogen. At present the soil nitrate-nitrogen test is available only for corn (maize) and barley. The results of soil nitrate-nitrogen tests from variable fields should be interpreted with caution.

Table 2-5 Summary of General BMPs for Applying Nutrients to Crops

Purpose	Practice
For Production and Profit	Apply exactly what crops need when they need it, maximize the benefit of nutrients by reducing losses, and apply where the nutrients will be used most efficiently.
For Practicality	Rotation may use nutrients not taken up by previous crop.
For Protection of the Environment	If the crop' s needs are met by applying nutrients in the right amount at the right time, there is no detriment to the environment.

Source: Canada, Agriculture and Agri-Food Canada (AA-FC), Ontario, Ministry of Agriculture, Food and Rural Affairs (OMAFRA), and Ontario Federation of Agriculture (OFA), 1996, *Best Management Practices, Livestock and Poultry Waste Management* (Toronto, ON: OFA; Canada, AA-FC et al.).

The nitrate-nitrogen levels can vary widely within some fields because of differences in past management, soil texture, organic matter content, drainage, or slope. In many fields it is impractical, if not impossible, to sample and fertilize different areas separately. The use of the soil nitrate-nitrogen test in such fields has not proven satisfactory.

Because of the specific issues around ammoniacal-nitrogen and nitrate in water, farmers are expected to consider the following factors when applying nitrogen:

- account for nitrogen available from all sources: soil, crop residues, manures, fertilizers, and carryover.
- where practical, soil-test for nitrate-nitrogen to determine crop requirements.
- when crop requirements are based on yield goals, set goals that are achievable in most years.
- apply most of the nitrogen near the time when the crop is growing most rapidly.
- avoid applying large amounts of material containing nitrogen in the late summer, fall, or winter. (Nitrogen can run off when it is applied to frozen ground and leaching or denitrification can be excessive if it is applied when no crop uptake is occurring.)
- on soils likely to have high nitrate levels, consider planting cover crops during periods when a commercial crop is not being grown.
- incorporate within 24 hours.
- nitrate is mobile and, if not quickly used by the crop, may be lost to the air or groundwater.
- it is recommended that no more than 75% of the crop needs for nitrogen come from manure.
- it is advantageous to include some nitrogen from mineral fertilizers, for the following reasons:

- nitrogen release from organic materials is dependent on the weather. In cool, damp seasons, the crop may not receive enough nitrogen from organic sources for optimum growth and yield.
- manure application is often uneven, so parts of the field may receive insufficient manure to meet crop requirements. A blanket application of mineral N fertilizer helps to increase overall yields by ensuring all the field has received sufficient nitrogen.
- reducing the N application rate from manure also reduces the amount of phosphorus being applied to rates closer to crop renewal or crop requirements.

For phosphorus, BMPs aim to

- reduce soil erosion,
- incorporate manure to reduce the impact of any runoff, and
- halt the application of manure where the soil already tests excessive.

2.5.3.2 *Key statements from OMAFRA publications*

The following subsections highlight key statements from various publications that provide substance to the approach advocated. Where possible, the appropriate Web site address is provided.

2.5.3.3 *Siting of livestock facilities in relation to land under different usage*

Minimum Distance Separation (MDS) is a land-use planning tool to determine a recommended distance between a livestock facility and another land use. The objective is to prevent land-use conflicts and minimize nuisance complaints that arise from incompatible land uses. MDS is primarily a zoning tool that does not explicitly account for noise and dust or the potential for ground or surface water contamination.

Ontario's MDS I guidelines provide minimum distance separation for new non-agricultural development from existing livestock facilities.[106] Ontario's

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[106] Ontario, Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 1995b, *Minimum Distance, Separation 1, (MDS I)* (Toronto, ON: Queen's Printer).

MDS II guidelines provide minimum distance separation for new or expanding livestock facilities from existing or approved development.[107] The differences between MDS I and MDS II applications are based on whether the proposed change in land use is due to a non-agricultural development in an area with existing agricultural operations (MDS I) or on whether the change is due to proposed changes in livestock operations in the area of an existing or already approved non-agricultural land-use activity. Thus, the distinctions recognize rights of prior uses.

2.5.3.4 *Manure handling and storage*

There are many good reasons to properly store and handle manure and other organic wastes. Farmers can profit because manure is a resource that will improve soil and supply nutrients to their crops. Animal and human contact with diseases and parasites found in wastes can be avoided. Drinking water supplies and fish habitats will not be contaminated. As well, properly stored manure and contaminated liquids are more efficient to manage.

Farmers are made aware that potential pollutants from manure include:

- coliform bacteria and nitrates that can contaminate water supplies;
- pathogenic bacteria that can cause disease in humans and livestock in extreme cases;
- phosphorus, which increases algae growth in watercourses, which can use up oxygen and kill fish; and
- manure odours that often bother neighbours.

Manure can pollute air and water in a variety of ways, such as:

- contaminated liquid can run from storage areas and exercise yards into surface and groundwater;
- manure stored on gravelly soils or shallow, cracked bedrock can pollute groundwater; and
- bacteria and other microorganisms in stored manure can produce gases when little or no oxygen is present.

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[107] Ontario, Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 1995c, *Minimum Distance, Separation II, (MDS II)* (Toronto, ON: Queen's Printer).

Options for collecting manure in the barn:

- BMP requires at least 240 days storage capacity

Types of storage

Liquid Manure Covered Rectangular Storage Advantages include the storage facility can act as a foundation for a barn, has good odour control, and reduces the addition of precipitation. Disadvantages include a potential manure gas hazard, a high cost for installation, and difficulty in agitation.

Covered Circular Storage Advantages include odour control and ease of agitation. However, this is also a costly system and impossible to expand.

Open Circular Storage Advantages include low cost, usable on all soil types, easy agitation and easily retrofitted with a cover. Disadvantages include limited odour control, difficulty in expansion, and precipitation adds to the volume.

Open Earthen Storage This is a low cost, easy-to-expand system. Disadvantages include poor odour control, a large surface area resulting in a high volume of precipitation entering, installation dependent on soil type, and difficult maintenance.

Solid Manure Roofed Rectangular Storage Advantages include a smaller manure volume because of no added precipitation, and only solid-manure handling equipment is required. Disadvantages include high cost, the difficulty of keeping the manure solid enough, the large amounts of bedding required, the possible deterioration of the roof, and the inability to accommodate extra liquids such as milkhouse wastes.

Mixed Storage Open Rectangular Storage with Separate Liquid Runoff Advantages include the ability to handle high volumes of bedding, a lower cost option if earthen liquid storage is used, and the ability to handle extra liquids such as milkhouse and parlour wastes. Disadvantages include the requirement for two manure handling systems, possible high cost if concrete liquid storages are required, and the difficulty of sizing if a portion of manure from livestock enters the liquid storage directly.

Additions of Non-manure Materials to Stored Manure It is important to manage all liquids. One of the greatest pollution risks comes from liquid manure around livestock housing facilities. Contaminated liquids other than urine include livestock housing washwater, runoff from the exercise yard, silo seepage, runoff from solid manure, milking centre washwater, and livestock watering wastes.

Including bedding with the manure has several benefits:

- it increases organic matter and improves soil-conditioning capabilities;
- it soaks up liquid and reduces loss of nitrogen to the atmosphere;
- it increases the carbon-nitrogen ratio and reduces the risk of organic nitrogen escaping into the air as manure breaks down; and
- it reduces the moisture content and allows more aeration which encourages composting.

Composting manure before application reduces the nutrients immediately available to crops. When manure is composted, it becomes a stable, humus-like material. Manure should not be composted on bare soil in open fields. It should be done on concrete in a roofed structure to prevent excessive leaching of nitrate.

2.5.3.5 *Land application*

A given field's suitability for manure application depends on a combination of topography, soil type, and vegetative cover. Application rates should include consideration of the total nutrient management requirements for the farm, according to crop and soil fertility. BMPs suggest the optimal timing of applications, as summarized in table 2.6. In general, factors to be considered when spreading manure include:

- preventing the loss of nutrients in surface runoff;
- reducing the loss of nitrogen into the atmosphere;
- minimizing soil compaction and problems with soil structure;
- eliminating oversupply of nutrients in soil caused by spreading manure on same ground each year;
- preventing leaching of nitrate into groundwater;
- reducing pollution of waterways by manure runoff or direct livestock access;
- minimizing odours during spreading;

Table 2-6 BMPs for Timing of Application

Months	BMP	Watch For
January to March	Manure should be going into storage, not onto fields. Do not spread manure onto frozen, bare or snow-covered land. Do not spread manure on land with a history of floods or run-off. Apply only in case of emergency onto grass or winter cover crops or on areas of high crop residue where there is no danger of run-off floods.	Runoff can pollute surface water. Use common sense and apply only on level, non-sensitive areas but only in emergencies.
April to May	Apply to land growing annual crops before seeding. Apply to row crops as a side dressing after plants come up. Irrigate or inject manure before planting corn to minimize soil compaction. Work manure into soil immediately (same day) after application to avoid loss of nitrogen. If application will cause excessive delays to planting because conditions are too wet, apply manure to white bean or soybean fields where yield will not be hurt as much by planting days.	Wet or surface-dry soil where the risk of compaction is high. Apply on coarse-textured best-drained fields first. Excessive application can create a pollution hazard. Very dry soil with large cracks where liquid manure can flow into drainage systems. Till over drains to avoid the problem. Seedbeds that do not dry quickly because of heavy surface residue. These soils will take that much more time to dry following application of liquid manure. Planting too soon after heavy manure application. This can create ammonia toxicity and reduce germination and seedling growth. Delay planting to the extent possible. Phosphorus in manure that is applied to soil surface after a crop is seeded may not be available to that crop. A soil test will indicate if another source of phosphorus is needed.
June and July	Apply to grasslands. Inject into grassland that will be plowed later. Inject liquid manure between rows of growing corn (June only) with a modified tanker. Apply solid and liquid cattle manure lightly onto hay fields after cuttings. Apply early enough to avoid tramping re-growth. Completely or partially compost manure before applying to reduce odour and break up clumps. Do not use manure on orchard grass/alfalfa mixtures. Orchard grass can crowd out alfalfa if manure is applied at this time.	Loss of nitrogen if there is no rainfall within 72 hours. Rain will help manure soak in. Consider an alternative application system like injection.

Table 2-6 BMPs for Timing of Application, cont'd.

Months	BMP	Watch For
August to October	Apply to grassland with no history of run-off and floods. Apply to annual crop lands that will be planted with winter cover crops.	Denitrification in cold, wet soils. Apply to best-drained soils only or to land that will be seeded to cover crops. Mature crops that are not growing and do not need nutrients. Very dry soil with large cracks where fields have tile drainage system. Liquid manure may leach into drains very quickly. Till over drains before applications to break up deep cracks and pores in soil. Wet or surface-dry soil with a high risk of compaction. Apply to best-drained fields first.
November and December	Manure should be going into storage, not onto fields. Do not spread onto frozen, bare or snow-covered land. Apply, only in cases of emergency, on grassland, fields with high crop residue levels or winter cover crops where there is no risk of floods or runoff.	Runoff. Manure will soak in too slowly on wet fields. It will run off with excess water. Compaction. Soils are wet and prone to compaction at this time of year.

Sources: Canada, AA-FC et al., 1996, 1998.

- slowing the build-up of nutrients and bacteria in ponds, wells, and other waterways;
- spreading of manure on forage and pasture appropriately to avoid rejection by animals.

All crops will benefit from soil conditioning from adding manure. Some, however, make better use of nutrients that are changed to forms available to plants immediately after incorporation.

- Corn uses the nutrients in manure best because of its high demand for nitrogen.

- Grass hay and pasture respond well to manure because they demand nitrogen. These crops also reduce soil compaction and risk of surface runoff.

- Legumes such as alfalfa, trefoil, and soybeans can benefit from added phosphorus, potassium, and micro-nutrients if soil tests show low levels; however nitrogen is wasted.

- Cereals do not use as much nitrogen as grass and corn but still have significant needs.

Protection of water resources from land application All operations need to consider the protection of water resources. In addition, there is an increasing use of irrigation in Ontario. Irrigation, the practice of adding water to moisture-deficient soils, depends on reliable supplies of fresh, clean water from surface and groundwater sources. Farmers must be aware of the potential impacts of their irrigation systems on the quantity and quality of groundwater and surface water.

Cover crops are often recommended to protect soil from erosion and take up residual nitrogen left in the soil when cash crops are not normally growing. Green manure crops are short-term cover crops, used particularly after short-season crops such as peas.

Surface water Runoff causing soil erosion carries particulate and dissolved substances into surface water. Table 2.7 summarizes the relationships between soil type, land topography and the potential for surface water contamination from manure runoff.[108] Several BMPs are aimed at preventing surface runoff and erosion:

- reduced tillage systems, which include no-till (the practice of planting crops with no primary or secondary tillage separate from the planter operations), ridge-till (an alternative to no-till, a cultivator forms a ridge

Table 2-7 Potential for Surface Water Contamination from Manure Runoff

Soil Infiltration Rate (soil texture)	Surface Water Contamination Potential			
	Topography (Land Slope) within 150 m (500 ft.) of water			
	<0.5%	0.5–2%	2–5%	>5%
Fast (sand)	VL	VL	VL	L
Moderate (loam)	VL	L	L	M
Slow (clay loam)	L	M	M	H
Very slow (clay)	M	H	H	H

H = high risk, M = moderate risk, L = low risk, VL = very low risk
Sources: Canada, AA-FC et al., 1996, 1998.

[108] Canada, AA-FC, OMAFRA, and OFA, 1998.

in early summer and the next year's crop is planted directly onto the ridge), and simplified tillage such as chisel plowing or 'soil saving.'

- residue management, leaving at least 30% crop residue on the soil surface after planting. Residue cover moderates soil temperature and encourages higher earthworm populations which benefit the soil structure.

- crop rotations that alternate forage or cereal crops with row crops. The forage or cereal crops leave less soil exposed over the year, while the row crops leave the soil exposed for much of the year and return little residue to the soil.

- drainage of wet fields. Some soils in Ontario are naturally low lying or have high water tables and need drainage. Drainage also benefits crops and adds value to agricultural land. Surface drains remove water in shallow open ditches but have limited effect on the water table. They are usually used in fine-textured soil. Subsurface drains (tile drains) remove excess water from the soil profile. Water moves down to the tile drains by gravity.

- construct erosion-control structures, e.g., grassed waterways, water and sediment control basins, and diversion terraces, to manage concentrated flows of water.

- use strip cropping and buffer strips. Strip cropping is the practice of planting alternating strips of row crops with forages or cereal crops.

- till and plant crops across the slope where possible or use a system of contour cropping.

Soil erosion due to wind can also impact surface watercourses. The key BMP here is the formation of windbreaks. Trees are planted in strategic areas on the farm to act as barriers to the wind.

Groundwater The main approach of BMPs is to carry out good nutrient management planning. To avoid risk of bacterial contamination of wells and groundwater, the following guidelines for separation distances are followed:

- 15 m (50 ft.) for drilled wells with a steel casing greater than 30 m (100 ft.) in depth, and
- 30 m (100 ft.) for all other wells.

In fields with shallow soil (<1 m) over bedrock, or if the water table is less than 1 m from the soil surface at the time of manure application, it is recommended that farmers:

- schedule nutrients to meet crop needs,
- use lower rates,
- pre-till to reduce excess percolation, and
- monitor carefully following application.

Some fields are naturally slowly draining, and the water table can be found within the top metre of soil in the spring. BMPs that deal with such soils recommend that farmers:

- install drainage tile and/or surface drains;
- grow crops suited to wetter soil conditions or crops that are planted later in the growing season (e.g., soybeans, winter wheat);
- use seed treatment;
- use disease-resistant/tolerant crop varieties;
- use a reduced tillage system such as ridge tillage, which creates a zone of drier soil for plant growth;
- use tillage carefully to expose soil to the air for evaporation and soil warming;
- use crop rotations;
- include deep-rooted crops such as alfalfa, clover etc.;
- encourage earthworm population for macropore development by leaving residue on the soil surface;
- use timely tillage and field operations;
- minimize the tillage passes to reduce compaction; and
- consider planting the area to pasture or trees.

Methods To ensure proper application rates of manure and commercial fertilizers, farmers are advised to calibrate their nutrient application equipment in combination with soil and manure testing and nutrient management planning. To do this calibration, farmers must take into account not only the number of loads being applied to a field but also the different densities of the manure or whether the spreader is being filled according to the manufacturer's specifications.

In addition, they must consider soil compaction that may occur under spreaders, since this can increase runoff. BMPs that lessen the impact of compaction on soil structure recommend:

- timely tillage and field operation: stay off wet fields, soil should be at proper moisture conditions at tillage depth;
- good drainage: tile drainage should be installed in fields with variable drainage;
- longer crop rotations that include forages/cereals;
- leaving forage crops in for longer than one year;
- that tillage equipment lifts and shatters soil (coulter chisel, cultivator) as opposed to pulverizing and grinding (disk);
- alternating tillage depth so tillage pans aren't created;
- limiting the amount of traffic, including tillage across a field;
- restricting compaction: create a long narrow "footprint" with tire arrangement, e.g., radials, large tires, tracks; and
- limiting axle loads to less than five tonnes per axle.

Soils shouldn't be worked in the spring until the soil moisture conditions drop below the 'lower plastic limit.' This is the minimum moisture point at which soils begin to puddle and the maximum point at which soils remain friable.

- In spring, manure should be applied before planting the most valuable crop.

- In summer, plan to side-dress growing row-crops on cereal stubble or between cuts of forages. To avoid crop damage, manure should not be spread on crop foliage.

- In winter, manure should go into storage. Winter application should only be considered if the storage is full (all recent livestock operations should have adequate storage). There is considerable risk of runoff with snowmelt, and no nutrient demand from crops at this time. The following must be taken into consideration:

- manure should not be spread on frozen bare (no cover crop) land;

- manure should not be spread when it is likely to run off, e.g., if a period of mild temperatures, rainfall, or wet snow is forecast for the ensuing 48 hours; and

- manure should be spread on a level field and kept away from watercourses. Ontario BMPs recommend separation distances between applied manure and surface water sources based on surface water contamination potentials given in table 2-7. Table 2-8 summarizes the recommended distances by type of application (surface-applied and incorporated) and by contamination potential. Also as a general rule, the distances recommended for spreading in other seasons should be doubled when spreading is done in winter.

Buffer zones and setbacks for watercourses Buffer strips or buffer zones are permanent borders on field boundaries or along watercourses that help reduce soil input into streams. Generally, narrower separation distances to watercourses are acceptable where:

- P levels are lower, and
- the risk of erosion and runoff due to soil type, cropping and tillage practices, slope, and distance to the watercourse is lower.

Contingency planning for manure spills A contingency plan includes the following:

- a list of emergency telephone numbers;
- a map showing surrounding dwellings and land uses;

Table 2-8 Minimum Separation Distances to Water Sources for Surface Water Contamination Potential from Liquid and Solid Manure Runoff

Surface Water Contamination Potential	**Separation Distance to Surface Water Sources metres (ft.)**			
	Surface-applied		Incorporated	
	liquid	solid	liquid	solid
High	30 (100)	15 (50)	18 (60)	9 (30)
Moderate	23 (75)	11 (37)	14 (45)	7 (22)
Low	15 (50)	8 (25)	9 (30)	4.5 (15)
Very Low	9 (30)	4.5 (15)	9 (30)	4.5 (15)

Note: the above minimum separation distances may be reduced to 9 m or 30 ft. (liquid) and 4.5 m or 15 ft. (solid) where the following practices are implemented.
Soil conservation techniques (e.g., mulch tillage, strip cropping, forages) are practised AND a minimum 3 m (10 ft.) wide vegetated buffer strip (measured from top of bank) exists along the perimeter of the surface water source.
For commercial fertilizers, a minimum separation distance of 3m (10 ft.) composed of a vegetable buffer strip should be established between the area of application and any water course.
Sources: Canada, AA-FC et al., 1996, 1998.

- a list of available emergency equipment and supplies and their locations;
- a sketch of the farmstead and immediate surroundings, including emergency water supplies;
- a sketch of the area surrounding the farm, indicating where surface and subsurface drainage water would flow; and
- specific plans outlining the action to be followed in the event of a manure or fertilizer spill.

One tool to help farmers develop sound manure management practices is the *Environmental Farm Plan* developed by the Ontario Farm Environmental Coalition (OFEC). The Ontario Farm Environmental Coalition recommends that farmers carry out self-assessment of their activities, identify those that result in environmental losses, and consider specific actions for reducing impacts on the environment.[109] The program is a voluntary educational program with limited financial resources to assist farmers in carrying out recommended actions. While a large number of farmers in Ontario have undertaken self-assessments as part of the Environmental Farm Plan, it is unknown as to the extent to which these farmers have undertaken activities that would reduce environmental impacts on their farms.

An electronic decision support system, *Nutrient Management 2000 (NMAN 2000)*, has been developed by OMAFRA and the University of Guelph to help producers develop good manure management skills. The field application component has been widely adopted by local municipalities to ensure that the land area available to a producer for applying manure allows all nutrients to be applied appropriately. The completion of such a nutrient management plan is commonly required before new barns can be built.

3 Biophysical Aspects of Manure Management

3.1 Background

Feed and water for livestock are the sources for mineral nutrients, metals, and pathogenic bacteria that are present in manure. If animals drink contaminated water, diarrhea can result,[110] which modifies the concentration of materials

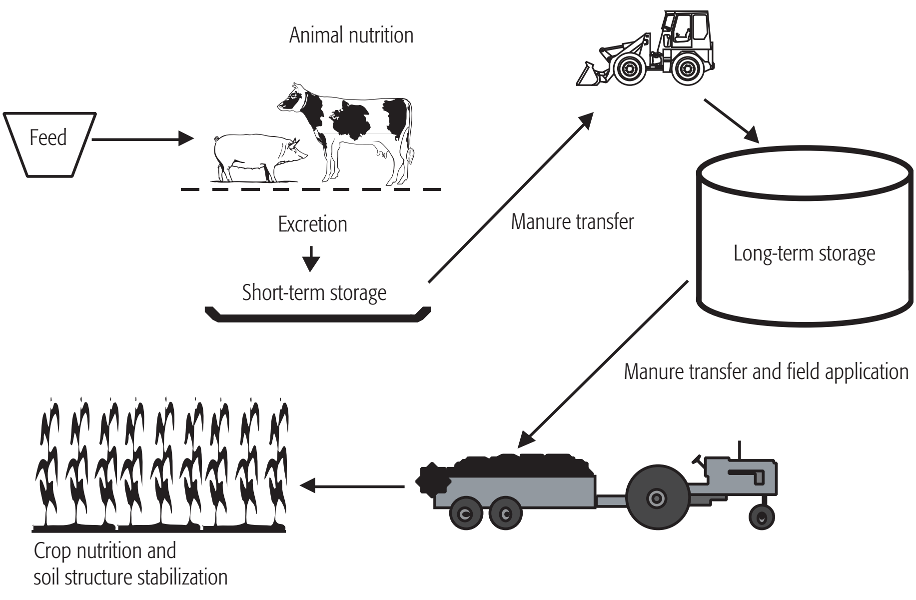
[109] More information about the Ontario Farm Coalition is available at <www.gov.on.ca/OMAFRA/english/environment/ofec/coalition.htm>. More information on the Environmental Farm Plan is available at <www.gov.on.ca/OMAFRA/english/environmental/efp/efp/htm>.

[110] D. Peer and W. Merritt, 1997, *Water quality and pig performance. Factsheet* (Guelph, ON: Ontario Ministry of Agriculture, Food and Rural Affairs).

within the manure. Water quality guidelines exist to protect animal health.[111] However, other than considering the transmission of pathogens between animals, there is little information on the impacts of animal manure on water quality.

Manure management should, and increasingly does, start with the formulation of the animal diets (figure 3-1). A properly designed diet provides all the nutrients and roughage required for growth, body maintenance, and reproductive capacity, while preventing unnecessary excess. Excess nutrients either pass through the alimentary tract and are excreted in the feces or are absorbed and then removed from the body, together with metabolic breakdown products, via the kidneys. In mammals, materials removed from the bloodstream by the kidneys are excreted along with water as urine. Avian species conserve water, and waste products separated by the kidneys are voided through the same opening as undigested feed.

Figure 3-1 The Main Parts of a Manure Management System that are Relevant to Environmental Contamination by Manure Constituents



[111] Canadian Council of Ministers of the Environment (CCME), 1999, "Canadian water quality guidelines for the protection of agricultural water uses: Summary table," *Canadian Environmental Quality Guidelines, 1999* (Winnipeg: CCME).

The alimentary tracts of animals provide ideal environments for microbial growth, including species and strains that are parasitic or pathogenic in humans. Part of the microbial population is voided along with the feces. The fate of these microbes, as well as that of the nutrients in manure, is considered in this section.

Most farm animals in Ontario spend significant time in confinement or at least under cover, so that most manure (the mix of urine and feces for mammals and the droppings of avian species) is deposited in barns or exercise yards. These locations provide an initial temporary store of the manure. In some cases, the manure is removed from the point of defecation and transferred into longer-term storage. Alternatively, it may be moved into short-term storage within the same area before being moved into longer-term storage. Sometimes, the manure undergoes treatment as part of long-term storage.

The manure of animals that graze or range freely is deposited directly on the land. Land application is also the main way to use stored manure. Spreading on the land is an important way to conserve the nutrients in the manure for crop production and reduce dependence on mineral fertilizers.

The fixed facilities where manure is deposited or stored can be considered as distinct potential point sources for the contamination of the environment and of water resources in particular. Fields where manure is deposited or purposely spread represent potential non-point or diffuse sources of contamination.

In this section, we consider all aspects of the potential for contamination of water resources from manure management systems, from feed manipulation to the production of crops, with a separate section for each component of the system (figure 3-1). A major section deals with the natural processes responsible for the movement of contaminants to water resources.

3.2 Potential Contamination and Manure Management Phase

3.2.1 Feed manipulation

The traditional approach of animal nutrition has been to ensure that a given feed regime supplied sufficient energy and protein to support metabolic energy and growth demands, and that other production functions (e.g., eggs laid, milk produced) were optimized. Manure was a waste product of this endeavour. Nutrients excreted were indicative of an inefficiency, but they could be recycled, at least in part, if manure was used to fertilize crops. The main nutrients in manure that are of concern for crop production are nitrogen (N), phosphorus (P), potassium (K), and carbon (C). With the exception of K, these same elements are important for water quality.

The feed provided for farm animals largely determines the potential for the contamination of water resources in subsequent phases of manure management. Large variations in the nutrient content of manure can be related to differences in levels of animal performance, feed intake, type and quality of diet and feed management, and environment factors affecting water and food intake.[112] Environment factors can also alter water and food intake by animals.[113] Depending on the type of livestock and their feeding regime, the typical recovery of feed N in manure has ranged from 72–89%.[114] Obviously, the efficiency of N-utilization could be improved and thereby result in less N in manure. For example, while corn grain is an energy feedstuff for pigs, it is deficient in several amino acids needed for growing animals. The main limiting amino acids are lysine and tryptophan, followed by threonine and isoleucine. Adding soybean meal to meet the lysine needs results in an excess of other amino acids in the diet. The excess amino acids are digested and the nitrogen is excreted via the kidneys. By feeding the synthetic amino acid L-lysine monohydrochloride, less soybean meal is required and less N enters the manure.

Animals have a much greater requirement for P than do plants. Some 80–85% of P in corn grain and about 75% in soybean meal is unavailable to non-ruminants (e.g., pigs and poultry) because they lack the enzyme phytase which cleaves the orthophosphate groups from the phytate molecule to release the P in a more easily digested form. P-needs are met by the addition of monosodium or dicalcium phosphate. Upwards of 65–75% of the total P in the diet may then be excreted.

Over the past decade, animal nutrition has focused on nutrient-use efficiency. Major strides have been made in understanding the impact of feed on the

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[112] American Society of Agricultural Engineers (ASAE), 1998, *ASAE Standards 1998*: *Standards, Engineering Practices, and Data,* 45th ed., (St. Joseph, MI: ASAE); J.B. Holter and W.E. Urban Jr., 1992, "Water partitioning and intake prediction in dry and lactating Holstein cows," *Journal of Dairy Science,* 75, p. 1472; H.H. Van Horn, A.C. Wilkie, and W.J. Powers, 1994, "Components of dairy manure management systems," *Journal of Dairy Science,* 77, p. 2008.

[113] Holter and Urban, 1992; Van Horn, Wilkie, and Powers, 1994.

[114] J. Azevedo and P.R. Stout, 1974, "Farm animal manures: an overview of their role in the agricultural environment," *Manual (California Agricultural Experiment Station),* 44.

nutrient content of animal excreta. Consequently, the feed industry has been changing rations and hence modifying the characteristics of manure. Some of the potential impacts of improving feed management are shown in table 3-1.

Increased efficiency in livestock production through improved feed conversion (essentially the amount of animal protein formed from a given amount of plant protein) can reduce the time that the animals are on the farm before being sent to market, and consequently reduce the amount of manure excreted per unit weight of meat produced. The impact of this on the total and regional production of manure is considered further in section 4.

By knowing the nitrogen content of the animal feed, one can predict the quantity of nitrogen excreted by the principal groups of farm animals.[115] The total

Table 3-1 Feed-related Measures Contributing to the Reduction in Pollution Caused by Animal Production

Changes in feeding regime	Possible reduction in nutrient content (%)	
	Nitrogen	Phosphorus
Supplements		
Increase use of supplementary amino acids and related compound combined with reduced levels of protein in feed.	20–25	–
Enzymes: Cellulase Phytase	5 –	– 25–30
Modified grains: high-available-P corn		25
Growth-promoting substances	5	5
Systems		
Precise feed formulation to animal needs	10–15	10–15
Phase feeding	15	15
Increased use of highly digestible raw materials	5	5

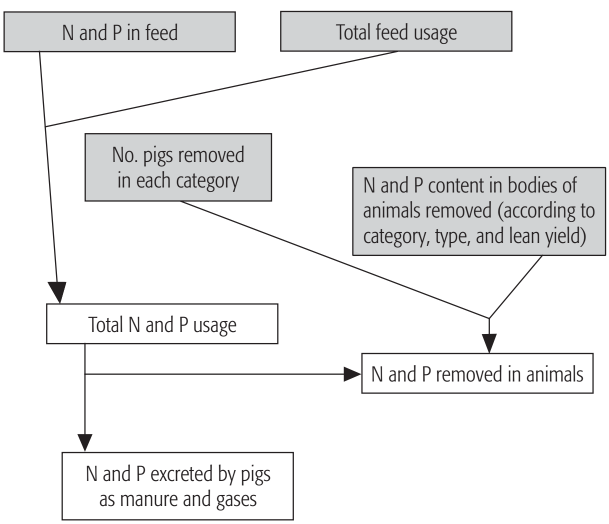
Sources: P. Williams, 1993 [personal communication]; C.F.M. de Lange, 1996, "Animal and feed factors determining N and P excretion with pig manure," *Managing Manure for Dairy and Swine. Towards Developing a Decision Support System,* M.J. Goss, D.P. Stonehouse, and J.C. Giraldez (eds.), (Fair Haven, NJ: SOS Publications).

[115] Kirchmann and Witter, 1992.

manure-N may be calculated by apportioning the nitrogen in the feed between the nitrogen assimilated by the animal and that excreted. For example, Charles developed a model that correlates the feed intake of hens to the numbers of eggs produced.[116] By analysing the feed and calculating the amount eaten, one can determine the nutrients available and predict egg production. The nutrient content of the manure is assumed to be the difference between the nutrient intake and that required for egg production.

In Ontario, hogs may be bred and raised for slaughter at the same unit (farrow-to-finish operations) or may be born in a farrowing unit, moved to a separate nursery unit and thence to a grower-finisher barn (segregated operations). On average, each sow farrows twice a year and produces 18 market pigs per year. This family unit excretes a total of 114 kg of N, 23 kg of P, and 70 kg of K. Approximately 70% of the nutrients are excreted by the grower-finisher animals. Feed intake can be used to predict the nutrient content of the manure (figure 3-2). The efficiency of nitrogen utilization by grower-finisher pigs can be best improved by making the dietary balance of amino acids closer to the pigs' required balance. More closely meeting the nutrient requirements during the various stages of growth (phase feeding) also improves the efficiency. For

Figure 3-2 Model to Predict N- and P-output in Pig Manure from the Feed Input and That Used for Pig Growth



Source: de Lange, 1996.

[116] D.R. Charles, 1984, "A model of egg production," *British Poultry Science,* 25, p. 309.

example, by manipulating the dietary amino acid balance, N-excretion in manure was reduced by 35% in grower pigs and 20% in finisher pigs without affecting animal performance.[117]

The largest improvements in phosphorus utilization by pigs are expected from phase feeding and improving P-digestibility.[118] As stated earlier, much of the P present in feed grains is in the form of phytates, which are not readily digested by non-ruminants. Although supplementary-P is commonly included in the diet of these animals to ensure an adequate supply, an alternative is to add the enzyme phytase to the diet to break down the phytate. At the University of Guelph, a genetically modified pig has been developed that secretes the phytase enzyme in its saliva. It is anticipated that commercial herds of such animals would not require supplementary-P in their diet. Another approach is the use of newly developed corn hybrids. These store P in a more available form in the grain. Feeding these "high-available-P" (HAP) hybrids can also reduce the need for supplementary-P and reduce the P excreted.

For ruminant animals such as cattle and sheep, the approach to promoting efficient feed conversion has been to vary the amount of protein and carbohydrate and improve the degradability (ease with which materials are broken down in the digestive tract) of components in the feed. This not only affects the amount of N, P, and K voided in manure, but also the proportion of N in feces relative to that in urine.

Tamminga concluded that 10–15% of the total N-intake is not utilized because of inefficiencies in amino acid utilization.[119] Microbial fermentation in the hindgut can result in more N being absorbed across the intestinal wall, thereby shifting the partitioning of N-excreted between feces and urine toward the latter. The N in urine is readily converted into mineral-N, whereas the N in feces is in a form that is converted only slowly to mineral forms.

Fecal excretion of P is primarily due to the unavailability of the phosphorus source in the diet and its turnover in the animal's body. P is an important

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[117] J.K. Tuitoek, L.G. Young, B.J. Kerr, and C.F.M. de Lange, 1993, "Digestible amino acid pattern for growing finishing pigs fed practical diets," *Journal of Animal Science,* 71 (suppl. 1), p. 167.
[118] A.W. Jongbloed, 1991, "Developments in the production and composition in manure from pigs and poultry," *Mest & Milieu in 2000,* H.A.C. Verkerk (ed.), (Wageningen, Netherlands: Dienst Landbouwkundig Onderzoek) (Dutch).
[119] S. Tamminga, 1992, "Nutrition management of dairy cows as a contribution to pollution control," *Journal of Dairy Science,* 75, p. 345.

constituent of all cells, where it participates in energy-storing and transporting processes. It is secreted in saliva and bile into the alimentary canal. Efficiency of P-absorption from feed, about 50%, varies with the feed source, amount of feed intake, calcium-to-phosphorus ratio, vitamin D status, intake of other minerals, intestinal pH, and age of the animal.[120] The availability of phosphorus decreases with the increasing complexity of the molecules containing it.[121]

For dairy cattle, one must consider the partitioning of nutrients into milk, calf, and metabolic maintenance. The improved genetic potential of dairy cows has resulted in increased milk production with increased feed intake.[122] If digestive parameters are similar, manure production would be expected to increase along with feed intake. Morse et al. compared estimates of total manure production, calculated using milk produced, feed intake, and either manure-N concentrations or total dietary nitrogen, with actual amounts collected from highly productive cows.[123] They found that the calculated values underestimated those observed by approximately 25%. Diet digestibility, moisture content, and level of intake influence the amounts of manure produced. Stress from heat and humidity increases water consumption, resulting in an increase in urine production.[124]

Equations developed to predict nutrient requirements for milk production can be reconfigured to estimate nutrient excretion into manure, using dietary intake, milk production, and stage of gestation of milking cows.[125] To derive information for the herd, one must also account for the growth of calves and young heifers and the body retention of nutrients in dry cows.

Metals derived from the diet are also present in some animal manures. Copper sulphate is used as a feed additive in swine and poultry to promote weight gain

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[120] D. Morse, H.H. Head, C.J. Wilcox, H.H. Van Horn, C.D. Hissem, and B. Harris, Jr., 1992, "Effects of concentration of dietary phosphorus on amount and route of excretion," *Journal of Dairy Science*, 75, p. 339.

[121] U.S. National Research Council (NRC), 1989, *Nutrient Requirements of Dairy Cattle* (Washington, D.C.: National Academy Press).

[122] Canada. Agriculture and Agri-Food Canada (AA-FC), 1995, *Dairy Animal Improvement Statistics* (Ottawa: Market and Industry Services Branch).

[123] D. Morse, R.A. Nordstedt, H.H. Head, and H.H. Van Horn, 1994, "Production and characteristics of manure from lactating dairy cows in Florida," *Transactions of the American Society of Agricultural Engineers,* 37, p. 275

[124] Holter and Urban, 1992; Morse et al., 1994; M.R. Murphy, 1991, "Water metabolism of dairy cattle," *Journal of Dairy Science,* 75, p. 326.

[125] U.S. NRC, 1989; J. Cant, 1999, *Algorithms in MCLONE4*, <www.oac.uoguelph.ca/ManSys/Software.htm>.

and feed efficiency.[126] Some of the increased feed efficiency is considered to result from a reduction in disease because of copper sulphate's fungicidal and bactericidal properties.[127] Supplemental zinc (Zn) for swine and poultry reduces the excessive accumulation of copper (Cu) in the liver and enhances general health and growth.[128] Generally, Zn is considered a safe mineral supplement, the animals tolerating high intakes. It is excreted primarily in feces.[129] Pigs utilize Cu with variable efficiency (20 to 40%), depending on its forms in the feed and animal age. Most excess Cu is eliminated through biliary excretions and hence into the feces.[130]

To act as growth promotants, Cu and Zn levels in swine diets are much higher than the minimum requirements for normal performance (5–25 ppm for Cu and 50–125 ppm for Zn, depending on the particular class of swine). In Canada, the federal *Feeds Act* limits the maximum level of Cu and Zn in the diet to 125 ppm and 500 ppm respectively, but in the United States, higher levels are common. In some countries, such as the Netherlands, growth-promoting levels of Cu and Zn are no longer allowed in finisher pig diets due to the impact on the environment.

Some other plant micronutrients are also added to feed, such as selenium (Se) and chromium (Cr). The latter may be added to pig feed (in the form of chromium picolinate) to reduce fat in the carcass.

The amount of microbial production in the hindgut of animals depends on the availability of fermentable carbohydrates and protein.[131] Diets that have slower rumen degradability of carbohydrates or faster passage rates provide greater quantities of these materials.

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[126] B. O'Dell, E.R. Miller, and W.J. Miller, 1979, *Literature Review on Copper and Zinc in Poultry, Swine and Ruminant Nutrition* (West Des Moines, IA: National Feed Ingredients Association); E.R. Miller, X. Lei, and D.E. Ulley, 1991, "Trace elements in animal nutrition," *Micronutrients in Agriculture,* 2nd ed., J.J. Mortvedt, F.R. Cox, L.M. Shuman, and R.M. Welch (eds.), (Madison, WI: Soil Science Society of America), p. 601.

[127] J.R.J. Sorenson, 1979, "Therapeutic uses of copper," *Copper in the Environment. Part II: Health Effects,* J.O. Nriagu (ed.), (New York: John Wiley & Sons), p. 83.

[128] I. Bremner, 1979, "Copper toxicity studies using domestic and laboratory animals," *Copper in the Environment. Part II: Health Effects,* J.O. Nriagu (ed.), (New York: John Wiley & Sons), p. 285.

[129] Miller, Lei, and Ulley, 1991.

[130] Miller, Lei, and Ulley, 1991.

[131] E.R. Orskov, C. Frazer, V.C. Mason, and S.O. Mann, 1970, "Influence of starch digestion in the large intestine of sheep on caecal fermentation, caecal microflora and faecal nitrogen excretion," *British Journal of Nutrition,* 24, p. 671.

Pathogenic bacteria can infect animals through contaminated feed and water supplies.[132] Contamination can come from the manure of other herd members or from other animals such as rodents. Diet, or at least changes in diet, appear to influence the shedding of *E. coli* O157:H7.[133]

Antibiotic drugs are used as feed supplements for poultry, swine, and beef and dairy cattle to improve the feed conversion to animal growth and production as well as to prevent and control disease. The antibiotics used, both subtherapeutically and for treating disease, include penicillin and tetracycline compounds. Ionophores, a type of antibiotic, depress or inhibit the growth of specific microorganisms in the rumen of cattle. This selective inhibition alters rumen processes, including changing the types of volatile fatty acids produced and decreasing the breakdown of feed protein. The improved animal performance associated with the use of ionophores results from the increased energy retention associated with the change from acetic acid to propionic acid production.[134]

The concern about the subtherapeutic use of antibiotics in animal husbandry hinges on the fact that some of these drugs are also used to treat humans. Antibiotic resistance in pathogenic bacteria has been the main focus of attention. Strains of *Clostridium perfringens* in manure (both pig and cattle) were found to have a high resistance to antibiotics. Their spread through the environment was related to land application of livestock waste.[135] Significant amounts of the ingested antibiotic can also be excreted in an active form.[136] There is also evidence that some antibiotics can increase shedding of *E. coli* O157:H7.[137]

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[132] D.E. Herriott, D.D. Hancock, E.D. Ebel, L.V. Carpenter, D.H. Rice, and T.E. Besser, 1998, "Association of herd management factors with colonization of dairy cattle by shiga toxin-positive *Escherichia coli* O157," *Journal of Food Protection,* 61, p. 802; J.A. Shere, K.J. Bartlett, and C.W. Kaspar, 1998, "Longitudinal study of *Escherichia coli* O157:H7 dissemination on four dairy farms in Wisconsin," *Applied and Environmental Microbiology,* 64, p. 1390.

[133] J.B. Russell, F. Diez-Gonzalez, and G.N. Jarvis, 2000, "Effects of diet shifts on *Escherichia coli* in cattle," *Journal of Dairy Science,* 83, p. 863.

[134] W.G. Bergen, and D.B. Bates, 1984, "Ionophores: Their effect on production efficiency and mode of action," *Journal of Animal Science,* 58, p. 1465.

[135] R. Van Stappen, F. Huysman, and W. Verstraete, 1990, "Land application of piggery manure: The need for adequate expert systems to evaluate and control manuring practices," *Fertilization and the Environment*, R. Merckx, H. Vereecken, and K. Vlassak (eds.), (Leuven, Belgium: Leuven University Press), p. 264.

[136] H. Gamal-El-Din, 1986, "Biogas production from antibiotic-contaminated cow manure," *Biogas, Technology, Transfer and Diffusion*, M.M. El-Halwagi, (ed.), (New York: Elsevier), p. 720.

[137] C. Gyles, 2000, "*E. coli* O157:H7 – Global perspective," Canadian Cattleman's Association (CCA) *E. coli* O157:H7 Workshop, 27 and 28 Nov. 2000, Calgary, Alberta, p. 9.

3.2.1.1 *Summary*

Feed and water for livestock are the sources of the mineral nutrients, metals, and pathogenic bacteria that are present in manure. Research aimed at improving feed utilization has, as one consequence, shown how the nutrient loading into manure can be modified by diet and how the form of N may change with the partitioning between urinary and fecal excretion. Diet can also affect the microbial activity in the hindgut of cattle, which could influence the survival of pathogens. The potential role of antibiotics in the diet (either at therapeutic or subtherapeutic levels) in the release of pathogens into manure is of considerable importance. Adding Cu and Zn to animal feed helps improve feed utilization, but these elements are also excreted in manure.

3.2.2 Excretion

Nutrients, microbes, endocrine-disrupting substances, and metals – all potential contaminants of water resources – are excreted by animals in their manure.

Nitrogen is an important nutrient for plants and animals. In the form of nitrates (NO_3^-) or nitrites (NO_2^-), it is an important contaminant of drinking water. Excreted in both feces and urine, nitrogen occurs in many forms ranging from urea and uric acid to complex cellular constituents. The major form of urine-N is urea (uric acid in birds), although up to 35% may be present in other forms such as allantoin, hippuric acid, and creatinine.[138] The relative agronomic importance of these different forms of N is unknown. Soon after excretion, urea and uric acid are thought to change rapidly to ammonium nitrogen.

Carbon compounds in feed are broken down during aerobic cell respiration to provide energy for the animals. However, if such compounds enter a water course as manure, they generate a large demand for oxygen in the microorganisms that feed on them (biological oxygen demand or BOD). Swine manure, for example, generates a very large BOD, ranging between 70,000 and 200,000 mg/L. This strong demand for oxygen by microorganisms can seriously deplete the amount in water bodies so that fish die through lack of oxygen.

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[138] D.C. Whitehead, D.R. Lockyer, and N. Raistrick, 1989, "Volatilization of ammonia from urea applied to soil: Influence of hippuric acid and other constituents of livestock urine," *Soil Biology & Biochemistry,* 21, p. 803; R.J. Thomas, K.A.B. Logan, A.D. Ironside, and G.R. Bolton, 1988, "Transformations and fate of sheep urine -N applied to an upland U.K. pasture at different times during the growing season," *Plant and Soil,* 107, p. 173.

Little is known about the amount of carbon excreted in relation to its level in feed. Beauchamp and Voroney estimated that 15–50% of the feed-C is excreted, depending largely on the kind of feed, livestock, and feed quality (digestibility).[139] The ability of ruminants to break down cellulose and complex starches in the alimentary tract also means that their manure tends to have a higher bacterial content than that of non-ruminants.

The risk of contamination of water resources depends, at least in part, on where the manure is excreted, which depends on whether the animals are confined or allowed to graze freely.

3.2.2.1 *Direct excretion into water resources*

In Ontario, an attempt has been made to reduce manure contamination by reducing the opportunity for animals to defecate directly into rivers and streams. Nonetheless, many animals are allowed access to flowing water courses to drink. Seasonal behavioural studies show that animals do not spend extended periods of time in the water and usually void little urine or feces there (figure 3-3).[140] However, this normal pattern was not always followed, and on one day at each experimental site, considerably more direct defecation did take place.[141] Once voided, bacteria rapidly become attached to sediment on the stream bed, where they can survive for at least two months.[142] Few are present in the water beyond 50 m from the point of entry.[143] Access to streams also allows animals to disturb the sediment, causing the release of coliforms and other bacteria into the water. These coliforms likely originate from direct defecation into the stream, in runoff and sediment from the adjacent fields, or from other sources such as waste treatment plants. Enhanced flow associated with major rainstorms also moves bacteria downstream.[144]

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[139] E.G. Beauchamp and R.P. Voroney, 1993, "Crop carbon distribution to soil with different cropping and livestock systems," *Journal of Soil and Water Conservation,* 49, p. 205.

[140] I.J.H. Duncan, E.A. Clark, and K. Maitland, 1998, *Livestock Behavior in and near Watercourses in Ontario: 3 Year Summary,* [unpublished report] (Guelph, ON: Animal and Poultry Science and Plant Agriculture, University of Guelph); H.L. Gary, S.R. Johnson, and S.L. Ponce, 1983, "Cattle grazing impact on surface water quality in a Colorado front range stream," *Journal of Soil and Water Conservation,* 38, p. 124.

[141] Duncan, Clark, and Maitland, 1998.

[142] C.M. Davies, J.A.H. Long, M. Donald, and N.J. Ashbolt, 1995, "Survival of fecal microorganisms in marine and freshwater sediments," *Applied and Environmental Microbiology,* 61, p. 1888.

[143] H. Whiteley, 1998, *Effects of cattle access on bacteria concentrations in streams,* [unpublished report], School of Engineering, University of Guelph.

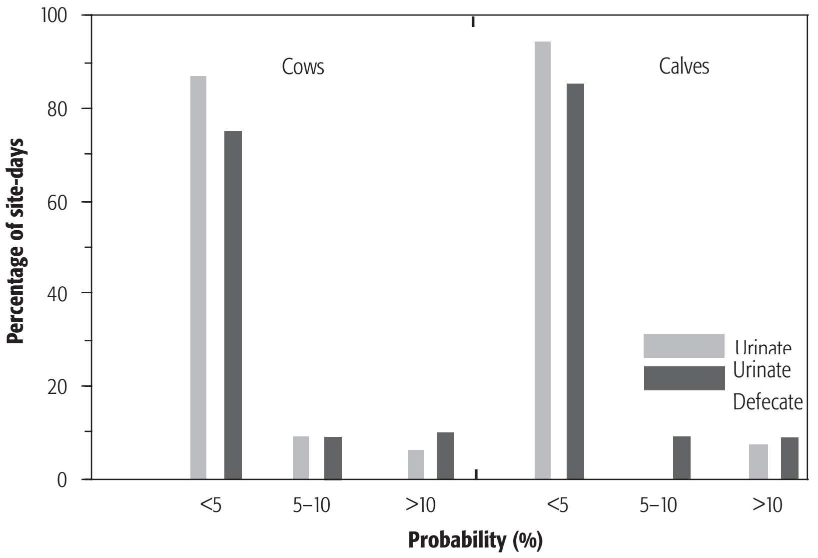
[144] Ibid.

Alternative methods to keep cattle away from water courses have been investigated. Fencing is effective but expensive. Providing drinking water in the field discourages access, as does preventing the animals from forming trails along stream banks. Providing shade away from streams may also help.[145] Constructing low-level crossings at locations normally used by animals to enter water can prevent collapse of banks and the disturbance of sediment.

3.2.2.2 *Excretion in confined or sheltered areas*

Ammonia from urine and bird droppings can be released into the atmosphere as a gas (volatilize) very rapidly after excretion, especially in areas where animals are confined. More nitrogen is lost by volatilization from within the barn than from other phases of cattle manure management in the UK.[146] Considerable volatilization of ammonia also occurs from uncovered yards if manure is not removed frequently.

Figure 3-3 Probability that Cows and Calves Will Void Urine or Feces into a Stream



Data for 52 site-days over three years from Ontario.
Source: Duncan et al., 1998.

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145 I.J.H. Duncan, 1996, *Observations of Cattle at Four Sites in Ontario during Summer 1995: Interim report,* [unpublished report] (Guelph, ON: Animal and Poultry Science, University of Guelph).
146 S.C. Jarvis, 1990, "Ammonia volatilization from grazed grassland: Effects of management on annual losses," *Fertilization and the Environment,* R. Merckx, H. Vereecken, and K. Vlassak (eds.), (Leuven, Belgium: Leuven University Press), p. 297.

Up to 23% of the ammonia may come from animal urine.[147] The release and volatilization of ammonia shortly after excretion reduces the final loading of N in the manure that is subsequently stored and eventually applied to the land.

Once manure is excreted, any pathogens it contains become subject to environmental stresses that can affect their survival. Some can still reproduce even though they are outside the body of the host animal. Some, such as *Clostridium perfringens*, form spores while others enter a resistant phase in which they fail to form colonies when attempts are made to culture them.[148] Other potential contaminants of water resources are unlikely to undergo transformation or growth, but their concentrations in manure may change as the carbon compounds are used as an energy source by microbes and other organisms.

3.2.2.3 *Mineral nutrients and labile carbon compounds*

Most of the information on the nutrient content of manure (see table 3-2) comes from stored rather than freshly excreted material.

Values for BOD concentration in fresh or stored manure are rare, but a few people have reported values in the range of 20,000 to 30,000 mg/L. Based on

Table 3-2 Characteristics of Different Types of Manure in Ontario

Animal Category	Range of dry matter content %	Range of values for nutrient content %			NH_4-N mg/L
		N	P	K	
Beef cattle					
solid	18–63	0.45–1.00	0.10–0.25	0.30–1.00	30–1050
liquid	1–13	0.10–0.50	0.02–0.25	0.10–0.25	700–2100
Dairy cattle					
solid	17–32	0.55–0.85	0.10–0.20	0.35–0.60	950–1350
liquid	1–13	0.10–0.40	0.02–0.20	0.10–0.40	650–1900
Pig					
solid	17–51	0.80–1.75	0.40–1.25	0.25–1.25	1700–4000
liquid	1–13	0.20–0.85	0.05–0.35	0.10–0.35	1500–5450
Poultry					
solid	16–90	0.90–3.20	0.40–1.45	0.35–1.60	3221–6450
liquid	0.5–12	0.15–0.90	0.02–0.35	0.01–0.35	900–6250

Source: C. Brown, 2000 [personal communication], November.

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[147] B.F. Pain, S. Jarvis, and B. Clements, 1991, "Impact of agricultural practices on soil pollution," *Outlook on Agriculture*, 20, p. 153.
[148] Davies et al., 1995.

the amount of manure per 1,000 kg live animal weight, swine and poultry contribute more material that generates BOD than do dairy and beef cattle (table 3-3).

A significant amount of the N lost by volatilization of ammonia immediately after excretion may be redeposited on fields surrounding the barn, while some is deposited at a much greater distance. In both cases, no control can be exercised over the deposition, which is also recognized as a part of acid rain.

The proportion of phosphorus (P) in organic form is greater in solid manure than in liquid manure. Liquid manure-P can occur as particulates such as trimagnesium phosphate[149] or as soluble components such as orthophosphates and low-molecular-weight organic phosphorus compounds. Poultry manure tends to contain the largest concentration of total-P while cattle manure tends to contain the lowest level.[150] Leinweber found that the total-P in dry poultry manure is less than in liquid swine manure, but the proportion of soluble-P was greater in poultry manure.[151] Swine slurry tends to contain more than double the amount of P present in cattle slurry.[152] The total-P excreted per 100

Table 3-3 Manure Production and Characteristics (per 1,000 kg Live Animal Weight per Day)

	Dairy	Beef	Swine	Poultry	
				Layer	Broiler
Total manure (feces + urine) (kg)	86	58	84	64	85
Total solids (kg)	12	8.5	11	16	22
BOD (kg)	1.6	1.6	3.1	3.3	NA*

* No data available.
Source: after ASAE, 1998.

[149] A.W. Fordham and U. Schwertmann, 1977, "Composition and reactions of liquid manure (gülle), with particular reference to phosphate: II Solid phase components," *Journal of Environmental Quality*, 6, p. 136.
[150] C. Tietjen, 1987, "Influence of faecal wastes on soil, plant, surface water and ground water," *Animal Production and Environmental Health*, D. Strauch (ed.), (Amsterdam: Elsevier Science), p. 203.
[151] P. Leinweber, 1997, "The concentrations and forms of phosphorus in manures and soils from the densely populated livestock area in north-west Germany," [poster], *Phosphorus Loss from Soil to Water*, H. Tunney, O.T. Carton, P.C. Brookes, and A.E. Johnston (eds.), (Wallingford UK: CAB International), p. 425.
[152] P. Schweiger, V. Binkele, and R. Traub, 1989, *Nitrat im Grundwasser: Erhebungen und Untersuchungen zum Nitrataustrag in das Grundwasser bei unterschiedlicher Nutzung, Massnahmen zur Reduzierung und Verhalten von Nitrat im Untergrund* (Stuttgart: E. Ulmer).

kg live animal weight per year was also greatest for poultry (approximately 12.8 kg/y), followed by pigs (6.2 kg/y), beef cattle (4 kg/y), sheep (2.6 kg/y), and dairy cattle (2 kg/y).[153] The use of phytase or high-available-P corn results in less P being excreted in pig manure compared with manure from pigs given a normal diet supplemented with mineral-P (table 3-1).

3.2.2.4 *Metals*

Manure may contain extra copper (Cu) and zinc (Zn) derived from feed additives. Evidence from Europe shows significant amounts of cadmium (Cd) and lead (Pb) in manure (table 3-4). Menzi and Kessler systematically

Table 3-4 Range of Metal Content of Manure from Swiss Farms

Animal Category	Manure Type	Copper	Zinc	Cadmium	Lead
			µg/g dry matter		
Cattle					
Dairy	Liquid	13–160 (88)	102–395 (267)	<0.08–3.2	1.3–50
	Solid	2.5–80 (42)	40–412	0.04–3.1	0.09–15.6
Beef	Liquid	36–870	88–938	<0.08–0.80	0.3–14.2
	Solid	15–51	48–448	<0.08–0.62	1.3–11.9
Swine					
Finishers	Liquid	30–376 (774)	337–2490 (1806)	<0.08–0.51	0.9–15.8
Nursery	Liquid	2281	2365		
Sows+litter	Liquid	12–1459	146–5832	0.06–1.3	0.34–12.8
Dry sows	Liquid	467	2067		
Sheep	Solid	13	104		
Poultry					
Layers	Solid (deep litter)	17–486	237–789	0.09–0.42	1.5–4.1
Broilers	Solid	80	320		

Data in brackets are sample values obtained in Ontario. Source: Brown, 2001.
Source: after Menzi and Kessler, 1998.

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[153] E.P. Taiganides, 1987, "Animal waste management and wastewater treatment," *Animal Production and Environmental Health,* D. Strauch (ed.), (Amsterdam: Elsevier Science), p. 91.

investigated the metal content of manure from 1992 to 1997 in Switzerland.[154] Their results show considerable variation between the sources and types of manure (table 3-4). Values from the United Kingdom for metal content lie within the range of those reported for Switzerland.[155] There has been no systematic analysis of metals in manure from Ontario, and those values, which have been collected by OMAFRA, suggest that for dairy manure the results are within the same range as those in European samples. However, Cu values for swine appear to be well above the range reported for Europe (table 3-4).

Other studies have also reported variability in the metal content of manure similar to that shown in table 3-4. For example, the total amount of Cu was found to be similar or even slightly greater in fresh poultry manure compared with fresh liquid swine manure,[156] but on a dry matter basis the percentage was over six times greater in swine manure.[157] More soluble Cu was present in liquid swine manure than in poultry manure. Cu and Zn are found in equal proportions within swine manure, but the level of Zn may be more than four times that present per unit of dry matter

Table 3-5 Copper and Zinc Content of Liquid Manure from Different Animal Categories

Animal Category	Copper mg/L	Zinc mg/L
Dairy	Trace (4)	0.1–0.2 (14)
Beef	0–0.1	0.1–0.3
Poultry	0–1.0	0.1–0.3
Swine	0.1–2.2 (29)	0.4–1.8 (50)

Source: Taiganides, 1987.

[154] H. Menzi and J. Kessler, 1998, "Heavy metal content of manures in Switzerland," *RAMIRAN 98. Proceedings of the 8th International Conference on the FAO ESCORENA Network on Recycling of Agricultural, Municipal, and Industrial Residues in Agriculture,* Rennes, France, 26–29 May 1998, J. Martinez and M. Maudet (eds.), (FAO and Cemagref, France), p. 495.
[155] B.J. Chambers, F.A. Nicholson, D.R. Soloman, and R.J. Unwin, 1998, "Heavy metal loadings from animal manures to agricultural land in England and Wales," *RAMIRAN 98. Proceedings of the 8th International Conference on the FAO ESCORENA Network on Recycling of Agricultural, Municipal, and Industrial Residues in Agriculture*, Rennes, France, 26–29 May 1998, J. Martinez and M. Maudet (eds.), (FAO and Cemagref, France), p. 475.
[156] J. Japenga and K. Harmsen, 1990, "Determination of mass balances and ionic balances in animal manure," *Netherlands Journal of Agricultural Science,* 38, p. 353.
[157] D. Strauch, 1987, "Hygiene of animal waste management," *Animal Production and Environmental Health*, D. Strauch (ed.), (Amsterdam: Elsevier Science), p. 155; Taiganides, 1987.

in poultry and cattle manure. Taiganides also found that cattle in the USA excrete only trace amounts of these metals (table 3-5).[158]

As long as dietary levels of Cu and Zn meet the minimum requirements for animal health, the excretion of these metals in pig manure is not generally considered an environmental concern. The concentration of Cu in swine manure from Ontario (table 3-4) would suggest, however, that more than the minimum requirement is being provided in the feed.

3.2.2.5 *Pathogens*

Animal manure can be the source of pathogenic organisms such as bacteria (tables 3-6, 3-7), viruses, protozoa, and helminthic worms.[159] The microbial population in the animal alimentary tract comprises both long-term colonizers as well as more transitory strains. As a result it is not always easy to identify the source of a contamination event in the environment. This may influence the design and selection of appropriate policy instruments to protect water quality (see section 2.2.2). As well, relatively few pathogenic organisms are found in manure compared with organisms that have no effect on human health. Furthermore, pathogens may be present in manure even if the animals present no symptoms, and a few infected animals can contaminate a whole source of manure.[160] Consequently the more animals on a farm, the greater the likelihood of pathogens being present in the manure.

Table 3-6 Examples of Pathogenic Bacteria Found in Animal Manure

Manure Type	Bacteria Species
Cattle	*Brucella* sp., *Bacillus anthracis (anthrax), Leptospira* sp., *Salmonella* sp., *Mycobacterium* sp., *Escherichia coli, Clostridium perfringens*
Swine	*Brucella* sp.., *Leptospira* sp., *Treponema* sp., *Clostridium tetani, Mycobacterium* sp., *Escherichia coli, Salmonella* sp.
Poultry	*Salmonella* sp., *Pasteurella* sp., *Campylobacter* sp. *Clostridium* sp., *Listeria* sp., *Mycobacterium* sp.

Source: after Strauch, 1988.

[158] Taiganides, 1987.
[159] Strauch, 1987.
[160] D. Strauch, 1988, "Krankheitserreger in Fäkalien und ihre epidemiologische Bedeutung," *Tierarztliche Praxis, Suppl.*, 3, p. 21.

Bacteria Very large numbers of bacteria are present in manure, and may total 10^{10} organisms/mL in liquid manure. The greatest numbers are of fecal coliforms and streptococci (table 3-8). While bacteria species from these two groups are always present in manure, Salmonella (another important group of bacterial pathogens) is present occasionally, mostly in swine and poultry manure. The prevalence of bacterial pathogens, particularly *Salmonella*, is thought to be greater in swine and poultry manure than in cattle manure.[161] However, the numbers may be similar across species when comparisons are made per unit of dry matter. Due to the greater mobility of bacteria in the liquid phase compared with the solid phase, liquid manure tends to be more uniformly contaminated than solid manure.

Table 3-7 Frequency of Detection of Pathogenic Organisms in Cattle

Study Description	Organism	Proportion of Carriers
USA, two national studies and two studies at state level (Wisconsin and Washington) of cow feces [a]	*E. coli* O157:H7	Feces of mature cows: usually under 1% of the animals but as high as 5% Calves under 24 mths: 2.8%
Quebec, Canada, feces from slaughtered cows [b]	*Salmonella* sp. *E. coli* *Yersinia* sp.	18% of animals 99% of animals 18% of animals
Review of literature, based on fecal content [c]	*Campylobacter*	0% to 19% of animals
UK, three dairy cow herds [d]	*Campylobacter*	37% to 81% of animals
Switzerland, 67 larger cow herds [e]	VTEC (verotoxin producing *E. coli*) *Campylobacter jejuni* *Campylobacter coli* *Yersinia* sp.	78% of the farms; 43% of the animals 32% of the farms 19% of the farms; 3% of the animals 22% of the farms; 1.7% of the animals (infection limited to animals younger than 8 months)

Sources: [a] Pell, 1997; [b] A.A. Mafu, R. Hjiggins, M. Nadeau, and G. Cousineau, 1989, "The incidence of *Salmonella*, *Campylobacter*, and *Yersinia enterocolitica* in swine carcasses and the slaughterhouse environment," *Journal of Food Protection,* 52, p. 642; [c] M.J. Blaser, D.N. Taylor, and R.A. Feldman, 1983, "Epidemiology of *Campylobacter jejuni* infections," *Epidemiological Reviews,* 5, p. 157; [d] H.I. Atabay, and J.E.L. Corry, 1998, "The isolation and prevalence of campylobacters from dairy cattle using a variety of methods," *Journal of Applied Microbiology,* 84, p. 733; [e] A. Busato, D. Hofer, T. Lentze, C. Caillard, and A. Burnens, 1999, "Prevalence and infection risks of zoonotic enteropathogenic bacteria in Swiss cow-calf farms," *Veterinary Microbiology,* 69, p. 251.

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[161] Strauch, 1987.

As pathogenic species or strains are present in far fewer numbers than are the benign or beneficial ones, the non-pathogenic organisms are commonly used as indicators of fecal contamination in water resources. Total coliform counts, numbers of fecal coliforms, and the presence of *Escherichia coli* (*E. coli*) are all used in this way. Some strains of *E. coli* can cause disease. These strains are recognized by the presence of particular proteins or polysaccharides on the surface of the bacteria. One serogroup, the enteropathogenic *E. coli* (EPEC),

Table 3-8 Examples of Bacterial and Protozoa Numbers in Some Animal Manure

Manure Type	Fecal Coliforms	Fecal Streptococci	*Salmonella* spp.	Protozoa
[a] Liquid swine manure	$4.3x10^3$ to $1.3x10^5$			
[b]	$2.4x10^3$	$9.3x10^3$	0	
[c]	$9.5x10^4$ to $1.1x10^6$ *E. coli*	$7.2x10^4$ to $4.5x10^5$ Streptococci-D	0 to $1.5x10^3$ (*S. infantis*)	
[b] Liquid cattle manure	$2.4x10^3$	$9.3x10^3$	0	
[c]	$4.5x10^2$ to $1.5x10^6$ *E. coli*	$4.5x10^2$ to $9.5x10^5$ Streptococci-D	0	
[d] Dairy slurry	$6.3x10^4$ to $1.0x10^7$ Enterobacteria			
[b] Solid beef manure	$2.4x10^5$	$1.5x10^7$	0	
[a]	$1.9x10^6$ to $6.8x10^6$			
[d] Solid dairy manure	$2.0x10^5$ to $1.0x10^7$ Enterobacteria			
[e] Fresh cow manure	up to $1.0x10^9$			
[f]			up to $1.0x10^9$	
[g]				*Cryptosporidium parvum* From 25 to $1.8x10^4$ in healthy animals, $1x10^{10}$ in sick animals

Sources: [a] A. Unc, 1999, *Transport of Faecal Bacteria from Manure through the Vadose Zone*, M.Sc. thesis, University of Guelph, Ontario; [b] T. Weigel, 1995, *Untersuchungen des Infiltrationsverhaltens von Mikroorganismen in Böden mittels Gruben- und Laborversuchen sowie eines selbst entwickelten Prototyps zur probennahme ohne Sekundärkontamination*, PhD dissertation, University of Hohenheim, Germany; [c] A. Rüprich, 1994, *Felduntersuchungen zum Infiltrationsverömgen und zur Lebensfähigkeit von Fäkalkeimen in Boden nach Gülledüngung*, PhD dissertation, University of Hohenheim, Germany; [d] Östling and Lindgren, 1991; [e] J.L. Mawdsley, R.D. Bargett, R.J. Merry, B.F. Pain, and M.K. Theodorou, 1995, "Pathogens in livestock waste, their potential for movement through soil and environmental pollution," *Applied Soil Ecology*, 2, p. 1; [f] N.A. Clinton, R.W. Weaver, L.M. Zibilske, and R.J. Hidalgo, 1979, "Incidence of salmonellae in feedlot manure," *Journal of Environmental Quality*, 8, p. 480; [g] C.A. Scott, H.V. Smith, and H.A. Gibbs, 1994, "Excretion of *Cryptosporidium parvum* oocysts by herd of beef suckler cows," *Veterinary Record*, 134, p. 172; K.W. Angus, 1987, "Cryptosporidiosis in domestic animals and humans," *In Practice*, 9, p. 47.

have given rise to *E. coli* O157:H7 which contains the genes for 'Shiga toxin' or 'Verotoxin.' These genes are thought to have been introduced through infection with bacteriophage (a virus that attacks bacteria), which carried the genes together with a virulence plasmid. Other disease-causing strains, developed from the enteroaggregative serogroup of *E. coli*, have also acquired the same toxin-forming genes and virulence plasmids. The Verotoxin-forming *E. coli* (VTEC) may therefore conform to O157 or non-O157 serogroups.

Not all *E. coli* with the O157 serotype actually give rise to disease in humans. However, cattle and other ruminants appear to carry those that do cause illness (table 3-9). Concentrations of *E. coli* O157:H7 in cattle feces range from 10^2 to 10^5 cfu/g fresh weight. The lower amounts are common in younger animals. Infection in an individual animal is not continuous; rather, animals experience a series of reinfections, the frequency declining with age. Furthermore, the release of *E. coli* O157:H7 in the feces shows a strong seasonality, being greatest in July and August. Consequently, the concentration of colony-forming units in feces is expected to be highly variable with time. Based on the surveillance of

Table 3-9 The Frequency of Detection of *E. coli* O157 in Animals from Different Groups

Animal Category	Range of reported frequency of detection (%)
Cattle:	
Dairy	0–68
Beef feedlot	0.3–88
Cow-calf	0.7–20
Sheep	0–31
Pigs	0–1.4 *
Poultry	0–1.3
Deer	1.9–9.0
Birds	0.5
Rodents	0–40
Flies	3.3
Horses	1.1
Pet dogs	3.1

* Not *E. coli* O157:H7.

Source: J. Van Donkersgoed, 2000, "North American primary production perspective," Canadian Cattleman's Association (CCA), *E. coli* O157:H7 Workshop, 27 and 28 Nov. 2000, Calgary, Alberta, p. 24.

beef carcass contamination, the concentration of *E. coli* O157:H7 in feces may vary between years as well as between seasons. *E. coli* O157:H7 has been detected infrequently in swine or poultry (table 3-9), probably giving less risk of human infection from these sources.

Other pathogenic bacteria

Leptospira, a waterborne pathogen spread through urine, has been found in pigs. Survival is enhanced by warm temperatures (19–30°C) and alkaline media.

Yersinia enterocolitica in humans is thought to come mainly from infected pigs. In Canada, its prevalence appears to be about 20% in finisher pigs.

Campylobacter spp. are commonly found in swine (66% to 95%) and poultry manure, but are of lesser concern in cattle. The frequency of infection in sheep tends to be less than in other farm animals.[162] *C. jejuni* has been isolated from chickens, pigs, and cattle in Ontario. Isolates from chickens and cattle were of the same serotypes that occur in humans. Most of the pigs that tested positive for *Campylobacter* carried a serotype of *C. coli* that was uncommon in humans.[163] Using laboratory-based microcosms (long-term testing units), Thomas et al. identified that water systems could act as a reservoir for *Campylobacter* infections.[164]

To prevent the colonization of poultry chicks by *C. jejuni*, 'competitive exclusion' can be used.[165] In this technique, a specific mixture of other intestinal bacteria, taken from adult birds, is introduced into the cecum of one-day-old chicks.

Listeria monocytogenes can be carried by healthy animals. Shedding of the bacterium is greater in winter than summer, and it can grow over a wide range of temperatures from 3–42°C. It is pH tolerant in the range of pH 5.5–9.0.[166]

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[162] P.A. Manser and R.W. Dalziel, 1985, "A survey of *Campylobacter* in animals," *Journal of Hygiene*, (London), 95, p. 15.
[163] D.L. Munroe, J.F. Prescott, and J.L. Penner, 1983, "*Campylobacter jejuni* and *Campylobacter coli* serotypes isolated from chickens, cattle, and pigs," *Journal of Clinical Microbiology,* 18, p. 877.
[164] C. Thomas, D.J. Hill, and M. Mabey, 1999, "Evaluation of the effect of temperature and nutrients on the survival of *Campylobacter* spp. in water microcosms," *Journal of Applied Microbiology,* 86, p. 1024.
[165] C.A. Phillips, 1995, "Incidence, epidemiology, and prevention of foodborne *Campylobacter* species," *Trends in Food Science and Technology,* 6, p. 83.
[166] A.N. Pell, 1997, "Manure and microbes: Public and animal health problem?" *Journal of Dairy Science*, 80, p. 2673.

Salmonella spp. are known to represent a risk to water supplies.[167]

Clostridium perfringens is a spore-forming bacterium whose spores are resistant to environmental stresses including disinfecting agents. It is excreted in the feces of many animals, but is not present in samples of sludge taken from septic tanks. Antibiotic-resistant strains of *C. perfringens* can be used to distinguish the source of fecal contamination of domestic farm wells; the presence of *C. perfringens* together with fecal coliforms indicated that animal manure was the source.[168]

Viruses Although viruses are common manure contaminants, information about their occurrence and longevity in manure is very limited. Many animal viruses that are likely to be excreted in manure do not cause disease in humans.[169]

Enteroviruses and adenoviruses in animals are not thought to represent a significant threat to humans.[170] Swine vesicular disease does not appear to pose a threat to water supplies. Survival outside the host appears to be relatively short. Bovine parvoviruses do not appear to be related to those that affect humans.

Some viruses, which do give rise to diseases in humans, can be found in large numbers in manure.[171] For example, coronaviruses, which cause diarrhoea in calves and pigs, are found in manure. Reoviruses excreted by cattle are found mainly in manure.[172]

Rotaviruses cause diarrhoea in neonates of humans and a number of other animals.[173] The closeness of the human and swine forms of rotaviruses, together with the analysis of associated antigens and antibodies, suggest a crossover

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[167] Ibid.

[168] M.J. Conboy and M.J. Goss, 2001, "Identification of an assemblage of indicator organisms to assess the timing and source of bacterial contamination in groundwater," *Water, Air, & Soil Pollution,* 29, p. 101.

[169] Pell, 1997.

[170] G.N. Stelma and L.J. McCabe, 1992, "Nonpoint pollution from animal sources and shellfish sanitation," *Journal of Food Protection,* 55, p. 649.

[171] P.B. Addis, T. Blaha, B. Crooker, F. Diez, J. Feirtag, S. Goyal, I. Greaves, M. Hathaway, K. Janni, S. Kirkhorn, R. Moon, D.E. Morse, C. Phillips, J. Reneau, J. Shutske, and S. Wells, 1999, *Generic Environmental Impact Statement on Animal Agriculture: A Summary of the Literature Related to the Effects of Animal Agriculture on Human Health*, University of Minnesota, Minnesota, USA, p. 134.

[172] Strauch, 1987.

[173] M.K. Estes and J. Cohen, 1989, "Rotavirus gene structure and function," *Microbiological Reviews,* 53, p. 165.

between the two hosts.[174] Large numbers of these viruses can be excreted in feces from infected pigs, with sows being an important source of contamination of young piglets.[175] Bovine rotaviruses may be isolated from cattle manure, but it is not thought to be common.[176]

Swine hepatitis E is closely allied to the human form of the virus. The virus is common in animals of three months or older throughout the mid-western U.S. states. The human form of the virus is known to be transmitted through contaminated water.[177]

Influenza virus is very widespread, and pigs may be a potential reservoir of human strains. The virus can survive outside the host for a prolonged period. For example, the infectious avian influenza virus can survive in water for 207 days at 17°C.[178]

Other animal viruses that can cause disease in humans, such as cowpox and paravaccinia, are not likely to be found in manure.

Protozoa Protozoan organisms, such as *Cryptosporidium parvum*, can also cause severe disease symptoms in humans. In one-third of the diarrheal outbreaks in 1993 to 1994 for which the causal agent was positively identified, *C. parvum* and *Giardia* species were the pathogens involved. River-water samples in the Ottawa region contained significant numbers of *C. parvum* oocysts and *G. lamblia* cysts, but the origin was likely from sewage treatment plants.[179]

Cryptosporidium parvum requires the ingestion of between 1 and 100 oocysts to cause disease in humans. It is considered a threat to surface water supplies, but

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[174] R.E. Holland, 1990, "Some infectious causes of diarrhea in young farm animals," *Clinical Microbiology Review,* 3, p. 345; N. Santos, R.C.C. Lima, C.M. Nozawa, R.E. Linhares, and V. Gouvea, 1999, "Detection of porcine rotavirus type G9 and of a mixture of types G1 and G5 associated with Wa-like VP4 specifically: Evidence for natural human-porcinegenetic reassortment," *Journal of Clinical Microbiology,* 37, p. 2734.
[175] D.A. Benfield, I. Stotz, R. Moore, and J.P. McAdaragh, 1982, "Shedding of rotavirus in feces of sows before and after farrowing," *Journal of Clinical Microbiology,* 16, p. 186.
[176] Pell, 1997.
[177] X.J. Meng, R.H. Purcell, P.G. Halbur, J.R. Lehman, D.M. Webb, T.S. Tsareva, J.S. Haynes, B.J. Thacker, and S.U. Emerson, 1997, "A novel virus in swine is closely related to the human hepatitis E virus," *Proceedings of the National Academy of Science*, 94, p. 9860.
[178] I.H. Brown and D.J. Alexander, 1998, "Influenza," *Zoonoses: Biology, Clinical Practice, and Public Health Control,* Lord Soulsby and D.I.H. Simpson (eds.), (Oxford: Oxford University Press), p. 365.
[179] C. Chauret, N. Armstrong, J. Fisher, R. Sharma, V.S. Springthorpe, and S.A. Sattar, 1995, "*Cryptosporidium* and *Giardia* in water in the Ottawa (Canada) region: Correlation with microbial indicators of water quality," *Journal of the American Water Works Association*, 87, p. 76.

recent evidence suggests that the oocysts can move through macropores in the soil and contaminate shallow groundwater.[180] *C. parvum* cannot be controlled by chlorination at levels that are safe for use in domestic water supplies.[181] Oocysts of *C. parvum* have been found in manure from dairy farms and swine farms in Ontario, although more were present in liquid manure from the swine farms. In the UK, oocysts were found on 59% of dairy farms and 22.4% of heifers and a similar number of beef calves were infected.[182] Fleming et al. examined the manure on 60 farms in southwestern Ontario on three occasions over one year.[183] *C. parvum* was found on 90% of the swine farms. Evidence suggests, however, that the strain associated with swine does not cause disease in humans.[184]

Giardia lamblia requires only about 10 cysts to cause disease in a human. It is the most commonly isolated intestinal parasite. In one study, 3% of young pigs and 19% of adult animals were infected.[185] *G. lamblia* has been found on 7–67% of swine operations.[186] There is evidence that *G. lamblia* from grazing cattle contributed to the contamination of a piped domestic water supply in British Columbia.[187] A surface reservoir was the source of the water.

Worms

Ascaris suum, a helminthic worm, appears to be able to pass from pigs to humans, although evidence from China suggests that the strains that infect pigs are genetically different from those isolated from humans. Prevalence in swine may be as high as 50%. Up to 2 million eggs can be shed per day by infected animals.

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[180] D.M. Endale, M.H. Young, D.S. Fisher, J.L. Steiner, K.D. Pennell, and A. Amirtharajah, 2000, "Subsurface transport of *Cryptosporidium* from pastures to surface waters: 1. Rationale and site description," *Annual Meeting Abstracts, ASA, CSSA, SSSA*, Minneapolis, Minnesota, November 5–9, p. 206.

[181] Pell, 1997.

[182] Ibid.

[183] R. Fleming, J. McLelland, D. Alves, D. Hilborn, K. Pintar, and M. MacAlpine, 1997, *Cryptospiridium in Livestock Manure Storages and Surface Waters in Ontario. Final report to Ontario Federation of Agriculture.*

[184] M. Olson, 2000, "Transmission and survival of *Esherichia coli* O157:H7." Canadian Cattleman's Association (CCA) *E. coli* O157:H7 Workshop, 27 and 28 Nov. 2000, Calgary, Alberta, p. 28.

[185] M. E. Olson, C.L. Thorlakson, L. Deselliers, D.W. Morck, and T.A. McAllister, 1997, "*Giardia* and *Cryptosporidium* in Canadian farm animals," *Veterinary Parasitology,* 68, p. 375.

[186] L. Xiao, R.P. Herd, and G.L. Bowman, 1994, "Prevalence of *Cryptosporidium* and *Giardia* infections on two Ohio pig farms with different management systems," *Veterinary Parasitology,* 52, p. 331.

[187] J. Issac-Renton, W. Moorehead, and A. Ross, 1995, "*Giardia* cyst concentrations and infectivity: Longitudinal community drinking water studies," *Protozoan Parasites and Water,* W.B. Betts, D. Casemore, C. Fricker, H. Smith, and J. Watkins (eds.), (Cambridge: Royal Society of Chemistry, UK).

Tenia solium, the human tapeworm, is very uncommon in North America, and is not thought to pose a risk to water supplies.

3.2.2.6 *Endocrine-disrupting substances*

Compounds with endocrine-disruption activity alter or affect various hormonal systems in animals, hence they are also referred to as hormonally active agents.[188] Long-term exposure can impair growth, development, and reproduction in fish, wildlife, and possibly even humans. A number of synthetic compounds, such as alkylphenols and alkylphenolethoxylates, have endocrine-disruptive activity. They are variously referred to as environmental estrogens or xenoestrogens. They appear to mimic the action of natural estrogens, which function to stimulate the growth of female structures and the development of secondary female characteristics. Relatively little work has been done to determine the environmental impact of natural estrogens. However, animal manure is known to contain significant amounts of these substances, which are produced mainly during reproductive phases.

An assessment of relative estrogenic potency suggests that estradiol-17β ranked first among a list of naturally occurring estrogens.[189] A soybean constituent, genistein, was given a potency of 1, but the potency of estradiol-17β was 10,000 to 20,000 times greater (table 3-10).

Table 3-10 Relative Potency of Some Endocrine-disruptive Substances

Compound	Relative hormonal potency based on oral dosing
Estradiol-17β	$1–2x10^4$
Estrone	$6.9x10^3$
Coumesterol	35
Genistein	1
Biochanin-A	0.46

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[188] L. Ritter, P. Sibley, K. Solomon, and K. Hall, 2002, *Sources, Pathways and Relative Risks of Contaminants in Water*, (Toronto: Ontario Ministry of the Attorney General), Walkerton Inquiry Commissioned Paper 10, Walkerton Inquiry CD-ROM. <www.walkertoninquiry.com>.

[189] G.W. Ivie, R.J. Christopher, and C.E. Munger, 1986, "Fate and residues of (4-14C) estradiol-17β after intramuscular injection into Holstein steer calves," *Journal of Animal Science,* 62, p. 681.

Estrogens are excreted in both urine and feces. Most of the estradiol-17β injected into steer calves was metabolized before being excreted in feces (57% of initial material) or urine (42% of initial material).[190] However, the metabolites also had estrogenic activity. Estradiol-17β is excreted by mature laying hens[191] in larger quantities than by non-laying birds (table 3-11).[192]

Table 3-11 Concentration of Endocrine-disruptive Substances in Animal Manure

Animal Category	Compound	Concentration (μg/g)
Poultry		
[a] Layer	Estrogen	1.6
[a] Layer	Estrogen	0.81
[b] Laying	Estradiol	0.53
[a] Broiler	Estrogen	0.33
[c] Broiler	Estradiol	0.13
Pigs		
[d]	Estradiol-17β†	0.01
[d]	Estrone†	0.02
[d]	Equol†	40
Cattle		
[b] Dairy	Estradiol plus estrone	91
[e]	Equol†	3
Beef	No data	
Horse‡		
[f]	Estradiol-17β	40

† Soluble fraction only, approximate dry-matter content used to obtain concentration
‡ Bedding present
Sources: [a] C.C. Calvert, L.W. Smith, and T.R. Wrenn, 1978, "Hormonal activity of poultry excreta processed for livestock feed," *Poultry Science*, 57, p. 265; [b] L.S. Shore, M. Shemesh, and R. Cohen, 1998, "The role of oestrodiol and oestrone in chicken manure silage in hyperoestrogenism in cattle," *Australian Veterinary Journal*, 65, p. 68; [c] Nichols et al., 1997; [d] Servos et al., 1998; [e] Burnison et al., 2000; [f] Busheé et al., 1998.

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[190] Ibid.
[191] H.F. MacRae, W. Zaharia, and R.H. Common, 1959, "Isolation of crystalline estradiol-17 from droppings of laying hens," *Poultry Science,* 38, p. 318.
[192] R.S. Mathur, and R.H. Common, 1969, "A note on the daily urinary excretion of estradiol-17 and estrone by the hen," *Poultry Science,* 48, p. 100.

Estrone excretion was also greater in laying hens, and showed a peak at or near the day that the first egg was laid.[193] Manure from broiler chickens contained a mixture of estrogen (0.065 μg/g) and the male hormone testosterone (0.13 μg/g).[194]

The detection of equol (a metabolite of the plant-derived estrogens daidzein and formononetin) in swine and dairy manure indicates that some endocrine-disruptive compounds in the diet can contribute to the total loading in manure. Although relatively large concentrations of equol were found in manure, its relative potency is considered to be much smaller than that of estradiol-17β.[195]

3.2.2.7 *Summary*

Although manure can be excreted directly into streams by grazing animals, this is not a general phenomenon even in cattle with access to the streams. Nonetheless, it appears that cattle entry into streams can be limited without fencing if producers provide shelter and water away from the stream banks.

Data on the amounts of nutrients in animal manure is well documented for Ontario, but there is little information on the content of metals, pathogens, endocrine-disruptive compounds, and labile carbon compounds that might be associated with turbidity in water supplies. There is considerable seasonality in the release of *E. coli* O157:H7 into manure, with largest numbers being shed in July and August.

3.2.3 Initial handling of manure and its short-term storage

Nutrients are conserved best when the manure is deposited on a slatted floor. Barn ventilation does not strip the ammonia as quickly as when it is deposited on flat floors. The hydrolysis of urea to ammonia usually takes about two days, so the length of time the manure remains on the floor before being moved into storage is one factor affecting the N-loss at this stage.

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[193] R.S. Mathur, P.A. Anastassiadis, and R.H. Common, 1966, "Urinary excretion of estrone and of 16-epi-estriol plus 17-epi-estriol by the hen," *Poultry Science,* 45, p. 946.

[194] L.S. Shore, D. Correll, and P.K. Chakraborty, 1995, "Sources and distribution of testosterone and estrogen in the Chesapeake Bay Watershed," *Impact of Animal Manure and the Land-Water Interface,* K. Steele (ed.), (Boca Raton, FL: Lewis Publisher, CRC Press), p. 155.

[195] B.K. Burnison, T. Neheli, D. Nuttley, A. Hartmann, R. McInnis, A. Jurkovic, K. Terry, T. Ternes, and M. Servos, 2000, *Identification of Estrogenic Substances in Animal and Human Waste*, 27th Annual Aquatic Toxicity Workshop: St. John's, Newfoundland, Oct. 1–4, 2000.

The current information available through the Canada Plan Service (CPS) shows the latest designs for slatted floors and short-term storage (<www.cps.gov.on.ca/english/plan.htm>). The internal arrangements of pens, ventilation fans, animal walk alleys, feeders, and waterers are all aimed at keeping the defecation area as small as possible.

As indicated in section 3.2.2.2, nitrogen concentration in manures differs between species, feed, and the health of the animals. As well, the type, amount, and nutrient content of the bedding used and the amount of water added to manure from drinking water can modify the quality of the manure after defecation.[196] The consistency of manure depends on the type of animal as well as the feed contents, the water intake, and the amount of water and bedding mixed with the urine and feces. If the mixture contains less than 12% dry matter it can usually be handled as a liquid. Manure with a dry matter content of 10–16% may behave as a semi-solid material, making it difficult to handle. Above about 14% dry matter, manure generally behaves as a solid material and is more readily handled.

Surface water courses need to be protected from any runoff that might carry manure from feedlots and exercise yards. Many modern feedlots have lagoons to collect any runoff. Of the 229 manure spills recorded by the Ontario Ministry of the Environment (OMOE) that impacted surface water bodies in the Southwestern Region of Ontario between 1988 and 1999, 216 related to liquid manure systems and only three to solid manure systems.[197] Manure type was not recorded for the remaining spills.

3.2.3.1 *Nutrients*

Nitrogen The transformation of urea and possibly other compounds to ammonium occurs relatively rapidly, so substantial quantities of ammonia are lost in swine barns before the manure reaches storage. The loss varied from 5 to 27% of the excreted-N, depending on the duration of the residence period in the barn, the temperature, and the extent of ventilation.[198] Only limited information is available on the extent of ammonia losses from different manure management systems and how these losses may be reduced.

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[196] E.G. Beauchamp, 1983, "Response of corn to nitrogen in preplant and sidedress applications of liquid dairy cattle manure," *Canadian Journal of Soil Science,* 63, p. 377.
[197] M. Blackie, 2000, [Personal communication.] Agricultural Impact Specialist, Ontario Ministry of the Environment, London, Ontario.

Carbon It is expected that microbial degradation processes continue following the voiding of feces and urine, but little is known about the C-transformations that occur in the short term. For example, liquid manures contain more readily decomposable C-compounds[199] although little is known of differences in decomposition between liquid and solid manure. These readily decomposable C-compounds are, presumably, decomposed rapidly in 'aerobic' solid manure systems.

3.2.3.2 *Pathogens*

Bacteria Barn cleaning is aimed at improving animal welfare. However, alley-flushing systems resulted in an 8-fold higher rate of contamination with *E.coli* O157:H7 in dairy animals than was found for other cleaning systems.[200] *Salmonella agona* was found in 84% of swine fecal samples in an open-flush gutter barn compared with only 9% from pigs on a partly slotted floor.[201]

Viruses Once outside the host, viruses are unable to multiply. Their survival depends on the pH of their environment, temperature, and whether they are adsorbed onto suspended solids or embedded in them.[202] Viruses tend to be inactivated more rapidly in summer than in winter.

3.2.3.3 *Summary*

Initial handling of the manure of confined animals is a major factor in determining the final consistency of the manure. Gaseous losses of N can be significant at this stage. Although carbon compounds are known to undergo further degradation, little is known about the actual processes.

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198 E.G. Beauchamp and D.L. Burton, 1985, *Ammonia losses from manures,* OMAF Agdex 538.

199 J.W. Paul, 1991, *Corn Yields and Potential for Nitrate Leaching From Manures and Inorganic N Fertilizer,* Ph.D. thesis. University of Guelph, Guelph, Ontario.

200 L.P. Garber, S.J. Wells, L. Schroeder-Tucker, and K. Ferris, 1999, "Factors associated with fecal shedding of verotoxin-producing *Escerichia coli* O157 on dairy farms," *Journal of Food Protection,* 62, p. 307.

201 P.R. Davies, W.E. Morrow, F.T. Jones, J. Deen, P.J. Fedorka-Cray, and I.T. Harris, 1997, "Prevalence of *Salmonella* in finishing swine raised in different production systems in North Carolina, USA," *Epidemiology and Infection*, 119, p. 237.

202 Pell, 1997.

3.2.4 Long-term manure storage

Manure has to be stored for at least part of the year. There are two basic storage methods:

- keep the manure as dry as possible and store as solid or semi-solid material;
- add cleaning water and produce a slurry that can be handled as a liquid.

Implications for engineering and economics and the possibilities for treating the manure during storage differ markedly between solid and liquid systems.[203] Solid manure can be composted during storage or simply allowed to break down.[204] Major changes in the composition and the form of the nutrient fractions can result.[205] Liquid manure can also undergo transformations, particularly resulting in the release of gaseous products.[206] The consistency of liquid manure and the concentration of nutrients may be further modified on transfer to long-term storage if washwater from barn or milkhouse cleaning is added.

Various types of liquid storage are popular in Ontario. The majority are open top storage systems, considered to be the most economical construction. However, such storage facilities collect rain and snow while allowing free volatilization of ammonia. Cracks in liquid manure tanks and earthen storages can lead to groundwater pollution, although this may be small.[207] While clean water infiltrated through unsealed cracks into concrete storages from high water

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[203] S.F. Barrington and M. Piché, 1992, "Research priorities for the storage of solid dairy manures in Quebec," *Canadian Agricultural Engineering*, 34, p. 393; J.W. Paul, G. Hughes-Games, and B.J. Zebarth, 1992, *Manure Management Workshop*, Presented by: Agriculture and Agri-Food Canada, British Columbia, Ministry of Agriculture, Fisheries and Food, Soils and Engineering Branch, and Canada-British Columbia Soil Conservation Program.

[204] Anon.,1991, "The many views of composting," *The Biocycle Guide to the Art and Science of Composting*, The Staff of Biocycle (eds.), (Emmaus, PA. Jerome Goldstein Press Inc.), p. 270; G. Guidi and G. Poggio, 1987, "Some effects of compost on soil physical properties," *Compost: Production, Quality and Use*, M. De Bertoldi, M.P. Ferranti, P. L'Hermite, and F. Zucconi, (eds.), (Pisa, Italy: C.N.R. Institute for Soil Chemistry, Italy), p. 577.

[205] C.S. Baldwin, 1981, *A Barnyard Manure Story. A Summary of 20 Years Research* (Ridgetown, ON: Soil Section, Ridgetown College of Agricultural Technology); P.O. Ngoddy, J. Haper, R.K. Robert, G.D. Wells, and F.A. Heidar, 1971, *Closed System Waste Management for Livestock* (Washington, D.C.: U.S. Environmental Protection Agency); A. Wild, 1988, "Plant nutrients in soil: Nitrogen," *Russell's Soil Conditions and Plant Growth* (New York: John Wiley and Sons), p. 652.

[206] L.R. Webber and T.H. Lane, 1969, "The nitrogen problem in the land disposal of liquid manure," *Cornell University Conference on Agricultural Waste Management*, p. 124.

tables, the reverse flow was not as great.[208] When manure with 10% solids was in the tank, the leakage was greatly reduced (by more than 10:1). Even though leakage was slow, the products remained in the soil through which they flowed.[209] Once all the soil surrounding a well became contaminated, it was not practicable to clean it up.

Jofriet has developed new plans for the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) which attempt to present best practices in the design and construction of concrete underground storage.[210] Earthen storage, in areas with shallow bedrock, pervious soils, and shallow water tables, also endanger water supplies. Some townships require soils engineering to determine the depth of suitable soil; otherwise artificial liners are needed. Placing a storage tank above ground is not really a solution because of cost and the difficulty of filling and agitation.

Particular concern for groundwater quality relates to clay-lined lagoon storage units located on sandy loam or loamy sand soils with shallow water tables.[211] Unless properly constructed using impervious liners, manure liquids can leak into the subsoil.[212] If cracks develop in the walls of the liner after the lagoon has been emptied, newly added manure can seep out before solids can effect a reseal. Leaks can also develop if plant roots are allowed to penetrate the liner. Once manure has leaked out, ammoniacal nitrogen can be nitrified and organic nitrogen mineralized in the soil, resulting in nitrate that can move to the groundwater.

Problems with liquid manure storage systems contributed 17% of the 229 listed manure spills mentioned above.[213] The failures of storages in terms of cracks or collapse, although small in number, are of concern. Cracks in storage walls

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[207] J.G. Rowsell, M.H. Miller, and P.H. Groenevelt, 1985, "Self-sealing of earthened liquid manure storage ponds: II. Rate and mechanism of sealing," *Journal of Environmental Quality,* 14, p. 539; S.F. Barrington, J. Denis, and N.K. Patni, 1991, "Leakage from two concrete manure tanks," *Canadian Agricultural Engineering*, 32, p. 137.

[208] S.F. Barrington., P.J. Jutras, and R.S. Broughton, 1987a, "The sealing of soils by manure. I. Preliminary investigations," *Canadian Agricultural Engineering,* 29, p. 99; S.F. Barrington, P.J. Jutras, and R.S. Broughton, 1987b, "The sealing of soils by manure. II. Sealing mechanisms," *Canadian Agricultural Engineering.* 29, p. 105.

[209] Barrington, Denis, and Patni, 1991.

[210] J.C. Jofriet, 1992, *Structural Components for Concrete Manure Storage Tanks*, Report to OMAF, Guelph, ON.

[211] W.F. Ritter and A.E.M. Chirnside, 1990, "Impact of animal waste lagoons on ground water quality," *Biological Wastes,* 22, p. 39.

[212] Barrington, Denis, and Patni, 1991.

[213] Blackie, 2000.

have allowed manure to enter the soil. In the most prominent cases, manure entered a tile drain and flowed into a watercourse. Both earthen and concrete storages have been involved, but concrete storages were involved in the most prominent cases.[214] In 1999, Ontario Pork investigated 50 concrete storages for liquid manure. Eight of these warranted further detailed investigation to identify whether leakage or spills during transfer of manure to tankers was responsible for elevated nutrients in the soil close to the tanks.

Fleming et al. reviewed the leakage of manure from storage facilities.[215] They concluded that as long as Ontario guidelines[216] were adhered to, significant leakage was unlikely from either concrete or earthen storage facilities because of the self-sealing properties of manure. Engineering solutions are available to prevent problems associated with the transfer of manure from gutters in a barn to the long-term storage; this has been the cause of some spills.

The size of storage has been an important issue in relation to water quality. Inadequate storage volume was involved in 34 of 38 manure spills associated with problems from stored manure in the Southwestern Region of Ontario between 1988 and 1999. Three times as many reports were related to concrete storage facilities as to earthen ones.[217] Too little long-term storage (e.g., storage capacity of less than 180 days) also requires the spreading of manure on partly frozen ground and risks endangering surface water supplies (see Timing of manure applications, 3.2.6.2).

Solid manure can be stored where it is produced and then transferred to the field. Such a system rarely allows storage for more than six months. Another possibility is to regularly transfer the manure to a concrete pad, which may also have side walls and a roof to keep out snow and rain. If the storage is not roofed, runoff might develop. This must be addressed, preferably by containment in a liquid storage. Some farmers still store solid manure in windrows directly on the soil. These piles can be leached by precipitation, leading to nitrate contamination of groundwater. Phosphorus can also enter the soil and give rise to elevated concentrations close to the soil surface.

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[214] J. Johnson and D. Hilborn, 1999, *Interim Recommendations Regarding Tile Drains and Manure Storage Structures. Infosheet, September, 1999* (Guelph, ON: OMAFRA), <www.gov.on.ca/OMAFRA/english/livestock/swine/facts/info_interim.htm>.

[215] R. Fleming, J. Johnston, and H. Fraser, 1999, *Leaking of Liquid Manure Storages: Literature Review [for Ontario Pork]* (Ridgetown,ON: Ridgetown College, University of Guelph).

[216] Ontario, Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 1994b, "Earthen Storage Design and Construction," *Agricultural Pollution Control Manual* (Guelph, ON: OMAFRA).

[217] Blackie, 2000.

3.2.4.1 *Fate of manure nutrients during storage*

Liquid or slurry manure undergoes anaerobic decomposition unless it is artificially aerated. Solid manure undergoes mainly aerobic decomposition if loosely packed or anaerobic decomposition if tightly packed. Aerobic decomposition of manure organic matter results in the release of CO_2 and the formation of compounds that are more resistant to breakdown by microbes. When free oxygen is not present, organic matter is converted to low-molecular-weight C-compounds, mainly volatile fatty acids (VFA). Methane gas (CH_4) is also produced. VFA are a readily available carbon source for microorganisms under aerobic conditions.

Nitrogen Addition of straw to poultry manure caused no significant immobilization of N under anaerobic conditions.[218] Loss of N by volatilization from anaerobic manure was only 1% of initial N-content. During anaerobic incubation, pH ranged from 5.0 to 6.2, which may be the main reason for the very small amount of NH_3 volatilization losses. Kirchmann and Witter point out that addition of straw may therefore increase NH_3 volatilization loss if it results in improved aeration and a change from predominantly anaerobic to aerobic decomposition.[219] Using more straw in barns may also result in greater absorption of urine and a greater capture of N. Depending on the total amounts of these nutrients, there may be little change in the C:N ratio of the collected manure.

A clear relationship has been identified between the C:N ratio of a mixture of cattle manure and straw, and the N-loss occurring during three months' storage over the summer. Losses of N from manure with various C:N ratios were 39% for a C:N of 16, 27% for a C:N of 22, and 10% for a C:N of 33.[220]

In a review of N-losses from farmyard cattle manure piled on the soil, Kirchmann found that N-losses by leaching ranged from 4 to 6% from solid manure under a tarpaulin cover and 10 to 14% from unprotected piles.[221] For piles of solid cattle manure, between 71 and 87% of the N-leaching took place in the first

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[218] H. Kirchmann and E. Witter, 1989, "Ammonia volatilization during aerobic and anaerobic manure decomposition," *Plant and Soil,* 115, p. 35.
[219] Ibid.
[220] H. Kirchmann, 1985, "Losses, plant uptake and utilisation of manure nitrogen during a production cycle," *Acta Agriculturae Scandinavica, Supplementum,* 24, p. 77.
[221] Ibid.

20 days, and the concentration of N in the leachate gradually decreased over the 177 days of the investigation.[222] Covering the piles with plastic sheeting did not greatly reduce the total amount of N leached. However, the volume of leachate due to precipitation was very small during the first 20 days of the study, but increased with time. Dewes postulated that covering a manure pile would make it drier, and consequently N-loss by NH_3 volatilization would probably be increased by much more than the N-loss by leaching was decreased.[223]

For liquid manure, temperatures in outdoor, below-ground, covered storage tanks in Ontario follow an annual cyclic pattern. Slurry temperature in the storage tanks ranged from 2 to 25°C.[224] For cattle and pig slurry in outdoor tanks in Denmark, Husted found that a surface crust decreased the rate of CH_4 emission by an order of magnitude.[225] The crust was less effective when slurry temperature was high, apparently because the crust dried and became porous. Paul also reported greatly increased loss of N as nitrous oxide (N_2O) when there was a surface crust.[226]

Mineralization of organic-N in slurry during anaerobic decomposition increases NH_4^+-N concentrations in the slurry if little NH_3 is lost by volatilization. About 73% of the N in anaerobically fermented pig slurry was present as NH_4^+ compared with 49% in fresh slurry (table 3-12). In anaerobically fermented cattle slurry, about 58% of the N was present as NH_4^+.[227] Concentrations of NO_3^- and nitrite (NO_2^-) were zero in the pig and cattle slurries (table 3-13). Patni and Jui also reported that almost no NO_3^- and NO_2^- occurred in dairy cattle slurry stored in outdoor tanks, however, NH_4^+ concentrations increased by 10 to 20%.[228] This slurry had been stored in the barn for six weeks before

[222] T. Dewes, 1995, "Nitrogen losses from manure heaps," *Nitrogen Leaching in Ecological Agriculture* (Bicester, Great Britain: A B Academic Publishers), p. 309.
[223] Ibid.
[224] Patni and Jui, 1987.
[225] S. Husted, 1994, "Seasonal variation in methane emission from stored slurry and solid manures," *Journal of Environmental Quality,* 23, p. 58.
[226] J. Paul, 1999, "Nitrous oxide emission resulting from animal manure management," *Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems*, 3–5 March 1999, Banff, Alberta, R.L. Desjardins, J.C. Keng, and K. Haugen-Kozyra (eds.), (Agriculture and Agri-Food Canada; Alberta, Agriculture, Food and Rural Development), p. 216.
[227] H. Kirchmann and A. Lundvall, 1993, "Relationship between N immobilization and volatile fatty acids in soil after application of pig and cattle slurry," *Biology of Fertile Soils*, 15, p. 161.
[228] N.K. Patni and P.Y. Jui, 1991, "Nitrogen concentration variability in dairy-cattle slurry stored in farm tanks," *Transactions of the American Society of Agricultural Engineers*, 34, p. 609.

Table 3-12 Characteristics of Fresh and Anaerobically Fermented Pig Slurry

Characteristics	Fresh	Fermented
Dry matter (%)	10.1	9.8
pH	7.4	7
Total N (g/L)	8.8	9.6
Organic N (g/L)	4.3	2.5
NH_4-N (g/L)	4.5	7.0
Fatty acids (g/L)	24.0	37.3
Ratio C:total N	5.6	5.7
Ratio C:organic N	11.5	21.4

Source: Kirchmann and Lundvall, 1993

Table 3-13 Composition of Animal Dungs: Fresh and After Seven Months' Aerobic or Anaerobic Storage

	Organic Matter			Water Soluble	
	Org. C	Org. N	C:N	C	N
	mg/g ash-free dry matter				
Cattle					
Fresh manure	526	28.4	18.6	75.9	6.1
Anaerobic	500	25.2	19.9	3.7	27.3
Aerobic	517	37.9	13.6	8.5	3.6
Pig					
Fresh manure	542	34.2	15.8	117.0	10.3
Anaerobic	551	25.9	21.3	36.7	26.4
Aerobic	499	52.0	9.6	68.1	8.0
Poultry					
Fresh manure	492	61.8	7.9	148.0	7.5
Anaerobic	452	25.2	17.9	20.7	73.2
Aerobic	478	40.8	11.7	60.9	10.1

Source: Kirchmann and Witter, 1992

transfer into outdoor storage. In the colder seasons, NH_4^+ accumulated, while the warmer seasons resulted in increased rates of NH_3 volatilization.[229]

Distribution of nutrients in storage facilities is an important issue (e.g., table 3-14). In this example of under-floor storage, top-loading maintained larger concentrations of ammonia-N in the upper layer. Using fans to dry the manure in Barn B conserved nitrogen and reduced the amount that was at immediate risk of loss by volatilization.[230] For liquid manures, mixing before removal from storage is a normal procedure, but it is a time when odours are released. Even if mineral nitrogen is uniformly distributed in the storage, this may not be true for other forms. Concentrations of NH_3-N in an earthen storage receiving dairy manure and milkhouse washwater in New York State

Table 3-14 Characteristics of Poultry Manure Sampled at Different Depths in Deep-pit Storage

Sample Location	Dry Matter (%)	Total Kjeldahl N	Ammonia-N	pH
		% dry weight		
Barn A				
Top	38.2 ± 3.8	6.1 ± 0.6	3.0 ± 0.8	8.0 ± 0.6
Middle	48.3 ± 9.4	3.5 ± 1.1	1.0 ± 0.3	8.3 ± 0.2
Bottom	46.5 ± 14.2	4.1 ± 1.3	1.2 ± 0.8	8.0 ± 0.7
Barn B				
Top	57.2 ± 18.7	7.9 ± 1.8	1.7 ± 0.8	8.1 ± 0.3
Middle	56.6 ± 33.6	5.3 ± 1.2	1.7 ± 1.3	8.3 ± 0.2
Bottom	82.3 ± 3.4	5.4 ± 0.8	0.8 ± 0.2	7.7 ± 0.7
Barn C				
Top	27.7 ± 0.5	6.1 ± 0.6	3.3 ± 1.0	7.9 ± 0.7
Middle	31.3 ± 3.1	3.6 ± 0.7	0.8 ± 0.1	8.0 ± 0.3
Bottom	32.5 ± 1.5	3.0 ± 0.5	0.7 ± 0.3	8.1 ± 0.2

Source: Bulley and Lee, 1987.

[229] Patni and Jui, 1987.
[230] N.R. Bulley and K.W. Lee, 1987, "Effects of management on the nitrogen content of poultry manure," *Canadian Agricultural Engineering*, 29, p. 81.

were uniform with depth in the spring. Volatilization from the storage was probably inhibited by a surface crust layer that was several cm thick. Settling of solids caused elevated concentrations of total solids, fixed solids, and Kjeldahl-N at the bottom of the storage.[231] Solid manure in open storage tends to lose NH_4^+ from the outer layers, which then provide less nitrogen when applied to the field.[232] Mixing solid manure before application is time-consuming for the operator.

Other mineral nutrients Patni and Jui concluded the following from their investigation of the mineral content of dairy cattle liquid manure during anaerobic storage:[233]

- The total solids concentration in slurry can decrease during prolonged storage because of volatilization of some organic materials.
- In the absence of dilution, concentrations of dry ash and macronutrients increase due to a decrease of total solids. The dry mineral concentrations therefore vary as a function of age and the loss of total solids.
- Concentrations of P, K, Ca, and Mg on a dry-weight basis have a strong negative correlation with total solids in slurry.
- About 40 % of slurry ash consists of P, K, Ca, and Mg.

Annual NH_3-N loss from manure storages in Denmark have been estimated at 4.2 kg per beef animal and 25.5 kg per dairy animal. Losses from outdoor slurry storage accounted for 28% of the loss from the beef system and 47% of the loss from the dairy system.[234] These results were obtained using an empirical model, which also indicated that decreasing the NH_3 loss during storage might be of little benefit because it increased the NH_3 loss during the field application phase.

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[231] R.E. Muck, G.W. Guest, and B.K. Richards, 1984, "Effects of manure storage design on nitrogen conservation," *Agricultural Wastes*, 10, p. 205.
[232] R.G. Kachanoski, D.A.J. Barry, D.P. Stonehouse, and E.G. Beauchamp,1997, *Nitrogen and Carbon Transformations in Conventionally Handled Livestock Manure*, COESA Report No. RES/MAN-002/97 prepared for Research Branch, Agriculture and Agri-Food Canada.
[233] N.K. Patni and P.Y. Jui, 1984, *Changes in Mineral Content of Dairy Cattle Liquid Manure during Anerobic Storage*, Paper No. 84 (Saskatoon, SK: CSAE).
[234] N.J. Hutchings, S.G. Sommer, and S.G. Jarvis, 1996, "A model of ammonia volatilization from a grazing livestock farm," *Atmospheric Environment*, 30, p. 589.

Organic carbon compounds It has been observed that about one-quarter to one-third of manure-C may be lost as CO_2 or CH_4 during normal storage periods.[235] Thus C-transformations are obviously occurring, but the processes are poorly understood. Aeration of the manure is an important factor in determining carbon loss (table 3-13). Further research is needed to determine the magnitudes of C losses with different manure storage systems. Importantly, the loss of carbon at this stage contributes either carbon dioxide (CO_2) or methane (CH_4) to the atmosphere, and both are greenhouse gases.

3.2.4.2 *Fate of pathogens*

The temperature, water content, and aeration status of manure are important for the survival of potential pathogens (table 3-15). In solid manure stores, pathogens close to the outside of a pile may be subject to cooler temperatures than are those near the centre. Consequently, the former may survive, even if those at the centre do not, and form the source for contamination when spread on the land.[236]

Bacteria The microbiological population in excreta undergoes considerable change during storage. Decomposition processes in manure are aerobic if free

Table 3-15 Survival of Potentially Pathogenic Organisms in Manure

Organism	Survival under experimental conditions (days)					
	Frozen	5° C	30° C	Liquid manure	Compost	Dried
E. coli	>100	>100	10	100	7	1
Salmonella	>150	150	28	75	14	7
Campylobacter	50	21	7	100	7	1
Giardia	<1	7	7	300	14	1
Cryptosporidium	>300	50	28	>300	28	1
		5° C	**22° C**	**37° C**		
E. coli O157:H7		70	56	49		

Sources: G. Wang, T. Zhao, and M.P. Doyle, 1996, "Fate of enterohemorrhagic *Escherichia coli* O157:H7 in bovine feces," *Applied and Environmental Microbiology*, 62, p. 2567; Olson, 2000.

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[235] Patni and Jui, 1987; P.J. Vanerp and T.A. Vandiyk, 1992, "Fertilizer value of pig slurries processed by the Promest procedure," *Fertilizer Research*, 32, p. 61.

[236] M.D. Sutton, 1983, "Phytopathogens and weed seeds in manure," *Farm Animal Manures in the Canadian Environment*, (Ottawa: National Research Council of Canada Associate Committee on Scientific Criteria for Environmental Quality), p. 109.

oxygen is present and anaerobic if free oxygen is not present. Aerobic microorganisms produce about 5.5 times more microbial biomass per unit of organic substrate than do anaerobic microorganisms.

Both cattle slurry and poultry excreta contain a high density of microorganisms.[237] The concentration of microorganisms (number per unit volume) in these manures is about 10¥ greater than in pig slurry. At the beginning of slurry storage, the population of viable organisms in most microbial groups abruptly declined.[238] Denitrifying and sulphate-reducing microbes, together with algae, increased during this time. Thereafter, the total population multiplied rapidly, becoming five-fold greater than the initial value after 14 weeks. The increase was mainly attributed to anaerobic bacteria (proteolytic, ammonific, amylolytic, anaerobic-cellulytic and anaerobic-nitrogen fixing species). Aerobic heterotrophic bacteria, actinomycetes, and fungi showed little change.

Viruses Rotaviruses are stable in feces for up to nine months. The longevity of other viruses can be adversely affected by some bacteria present in manure. These bacteria have developed various strategies to inactivate viruses, including the formation of proteases.[239]

Protozoa Cryptosporidium parvum oocysts were found to survive in liquid manure storages, despite the high levels of ammonium.[240] *Giardia* appears to be sensitive to freezing, whereas survival of other pathogens is enhanced. Temperatures above 30°C reduce survival times for these organisms, with the possible exception of *Giardia* (table 3-15). None of the organisms appear to survive for long in dried manure.

3.2.4.3 *Metals*

The percentage of Cu in the liquid fraction of swine manure increases slightly with storage time.[241] This is consistent with the loss of carbon and nitrogen in gaseous form (see section 3.2.2.2).

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[237] R. Nodar, M.J. Acea, and T. Carballas, 1990, "Microbial composition of poultry excreta," *Biological Wastes*, 33, p. 95.
[238] R. Nodar, M.J. Acea, and T. Carballas, 1992, "Poultry slurry microbial population: Composition and evolution during storage," *Bioresource Technology*, 40, p. 29.
[239] Pell, 1997.
[240] Flemming et al., 1997.
[241] Japenga and Harmsen, 1990.