At a field scale, even when sorption capacities in the surface horizon are exceeded and the water-soluble-P concentration become elevated, lower soil horizons may be able to sorb the leaching-P and minimize the potential for water-soluble-P movement to surface waters via drainage.[460] Similarly, immobilization of P on metal oxides (which can be present on the surface of particles within an aquifer) can decrease as the P-loading of soil increases.[461] However, preferential flow can be an important factor in tile-drain losses of particulate-P.[462] The importance of preferential flow for P-transport was confirmed by the fact that P was leached from the soil despite the large adsorption potential of some subsoils.[463] Although water-extractable-P was concentrated in the uppermost layer of the soil profiles at the time of most peaks in flow, P-concentrations in tile-drain effluents strongly increased with increasing flow rates.[464] Phosphorus was mainly transported as soluble-reactive and particulate-P through preferential flow paths extending from the soil surface to the drains. On clayey soils in an intensively cropped area in Quebec, up to 50% of the P lost through tile-drain effluent was in particulate forms, with less than 30% in soluble forms.[465]

3.3.5.3 *Metals*

Transport of metals through a soil is mostly a function of its acidity and concentration of dissolved oxygen. Accumulation of organic material close to the surface may possibly decrease the availability of Zn while increasing the solubility of iron and manganese.[466] Other studies show that although

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[460] T.L. Provin, B.C. Joern, D.P. Franzmeier, and A.L. Sutton, 1995, "Phosphorus retention in selected Indiana soils using short-term sorbtion isotherms and long-term aerobic incubations," *Animal Waste and Land-water Interface*, K. Steele (ed.), (Boca Raton, FL: CRC Press), p. 35.

[461] D.A. Walter, B.A. Rea, K.G. Stollenwerk, and J. Savoie, 1996, *Geochemical and Hydrologic Controls of Phosphorus Transport in a Sewage-contaminated Sand and Gravel Aquifer near Ashumet Pond, Cape Cod, Massachusetts* (Washington, D.C.: United States Geological Survey), Water-supply paper 2463.

[462] Heckrath et al., 1997; J.D. Gaynor and W.I. Findley, 1995, "Soil phosphorus loss from conservation and conventional tillage in corn production," *Journal of Environmental Quality*, 24, p. 734.

[463] Eghball, Binford, and Baltensperger, 1996; D. Thomas, G. Heckrath, and P.C. Brookes, 1997, "Evidence of phosphorus movement from Broadbalk soils by preferential flow," *Phosphorus Loss from Soil to Water*, H. Tunney, O.T. Carton, P.C. Brookes, and A.E. Johnston (eds.), (Wallingford UK: CAB International), p. 369.

[464] C. Stamm, H. Fluhler, R. Gachter, J. Leuenberger, and H. Wunderli, 1998, "Preferential transport of phosphorus in drained grassland soils," *Journal of Environmental Quality*, 27, p. 515.

[465] S. Beauchemin, R.R. Simard, and D. Cluis, 1998, "Forms and concentration of phosphorus in drainage water of twenty-seven tile-drained soils," *Journal of Environmental Quality*, 27, p. 721.

[466] L.M. Shuman, 1988, "Effect of organic matter on the distribution of manganese, copper, iron, and zinc in soil fractions," *Soil Science*, 146, p. 192.

the addition of organic material (in manure) to soil tends not to alter the total dissolved Zn, the Zn changes from being linked with low-molecular-weight organic particles to being associated with heavy organic particles. These heavy particles tend to be adsorbed by the soil complexes.[467] On the other hand, Cu interacts with dissolved organic carbon of low molecular weight, which is more likely to stay in solution and thereby increase the percentage of mobile Cu.[468]

Increases in the ionic concentration of the soil solution, as happens shortly after manure application, may decrease the percentage of metallic ions attached to soil mineral and organic particles by increasing the competition for adsorption sites.[469]

3.3.5.4 *Bacteria*

Bacterial transport is affected by soil pH. Long-term land application of cattle or pig manure can result in a decrease in soil pH.[470] This potentially reduces bacterial transport due to an increase in the number of binding sites available for bacterial adsorption. It may also affect bacterial survival. Cattle manure induced smaller soil pH changes compared with pig manure.

The moisture content of the soil prior to rainfall is another important factor in water movement and consequently contaminant transport. Abu-Ashour et al. conducted a series of experiments to determine factors influencing bacterial transport through soil.[471] Their findings indicated that initial soil moisture was the critical variable in determining the extent of bacterial migration. In dry soil, none of the marked bacteria (biotracer) were detected below 87.5 mm. However, the biotracer travelled the full length of the soil columns (175 mm) if the soil was wet. If water was added after biotracer inoculation, the biotracer moved deeper into the soil. The actual depth depended upon how close to saturation the soil became after the addition of a given volume of water. The water may have increased

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[467] Del Castilho et al., 1993b.

[468] N. König, P. Baccini, and B. Ulrich, 1986, "Der Einfluß der naturlichen organischen Substanzen auf die Metallverteilung zwischen Boden und Bodenlösung in einem sauren Waldboden," *Zeitschrift Für Pflanzenernärung und Bodenkunde,* 149, p. 68; Del Castilho et al., 1993b.

[469] F.J. Stevenson, 1991, "Organic matter-micronutrient reactions in soil," *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. 145.

[470] Chang, Sommerfeldt, and Entz, 1991; Bernal et al., 1992.

[471] J. Abu-Ashour, C. Etches, D.M. Joy, H. Lee, C.M. Reaume, C.B. Shadford, H.R. Whiteley, and S. Zelin, 1994a, *Field Experiment on Bacterial Contamination from Liquid Manure Application, Final Report for RAC Project No. 547G* (Toronto: Ontario Ministry of Environment and Energy).

the soil water content sufficiently to allow the bacteria to move through the soil with percolating water. However, bacteria can be transported to depth even if the soil is not saturated.[472]

A further factor influencing bacteria transport following liquid manure application is the large concentration of salts present in manure. The salts may act as "bridges," allowing negatively charged bacteria to adsorb to negatively charged soil particles. High salt concentrations can also decrease the thickness of the diffuse double layers around soil colloids, thereby allowing bacteria access to surfaces to which they can adhere. The addition of rainwater dilutes the salt concentration, thus increasing the thickness of the double layer and possibly causing the flushing out of adsorbed bacteria.[473] This increases the number of bacteria that remain mobile in the soil solution and increases the risk to groundwater.

Harvey has shown that the transport of bacteria may be faster, slower, or similar to that of tracers, such as chloride or bromide, that are not transformed into other compounds.[474] Bacteria move through soils and aquifers by several mechanisms, including continuous, discontinuous, and chemotactic migration.[475] Much of the modelling effort has treated transport as a continuous process, which assumes passive transport of bacteria. However, bacterial movement through the subsurface, especially over substantial distances, may be discontinuous because of processes that temporarily remove bacteria from solution. Bacteria are removed from the flowing water by straining or by reversible sorption on solid surfaces. They are remobilized later. Discontinuous transport creates an apparent retardation of the bacteria relative to conservative tracers. Retardation factors as large as 10 have been reported for bacterial populations travelling through porous aquifers.[476]

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[472] S.W. McMurry, M.S. Coyne, and E. Perfect, 1998, "Fecal coliform transport through intact soil blocks amended with poultry manure," *Journal of Environmental Quality*, 27, p. 86; A. Unc, 1999, *Transport of Faecal Bacteria from Manure through the Vadose Zone*, M.Sc. thesis, University of Guelph, Ontario.
[473] Y. Tan, W.J. Bond, A.D. Rovira, P.G. Brisbane, and D.M. Griffin, 1991, "Movement through soil of a biological control agent, *Pseudomonas fluorescens*," *Soil Biology & Biochemistry*, 23, p. 821.
[474] R.W. Harvey, 1991, "Parameters involved in modelling movement of bacteria in groundwater," *Modelling the Environmental Fate of Microorganisms*, C.J. Hurst (ed.), (Washington D.C.: American Society for Microbiology), p. 89.
[475] G. Bitton and R.W. Harvey, 1992, "Transport of pathogens through soil and aquifers," *Environmental Microbiology*, R. Mitchell (ed.), (Toronto, ON: Wiley-Liss Inc.), p. 103.
[476] G. Matthess, A. Pekdeger, and J. Schroeter, 1988, "Persistence and transport of bacteria and viruses in groundwater: A conceptual evaluation," *Journal of Contaminant Hydrology*, 2, p. 171.

Bacteria may also travel significantly faster than chloride or bromide due to motility. Movement due to taxis (self-propulsion) is faster than that caused by random thermal (Brownian) motion. Motile bacteria penetrated Berea sandstone cores in the presence of a nutrient gradient up to eight times faster than non-motile ones.[477]

Bacteria may also appear to travel faster than conservative tracers for other reasons. Bacterial transport is restricted to macropores, whereas conservative tracers diffuse into the soil matrix as well as the larger pores. This may cause the average peak in bacterial concentrations to appear earlier than that of the conservative tracer. The bacteria are exploiting faster paths but can travel only during peak flow, whereas the average tracer concentration, moving through the soil matrix and macropores, would not peak until the majority had infiltrated through the soil matrix.[478] The impact of preferential flow on the velocity of bacterial transport, relative to the average pore water velocity, is evident from table 3-19. Near the soil surface, where the structure is more uniform because of tillage, bacteria move at a rate similar to the average pore water. Deeper in the soil profile, bacterial movement is much faster than the average pore water because they are concentrated in the preferential flow paths.

In addition to transport processes, the kinetics of bacterial population growth and decay must be considered in relation to the timing and numbers of

Table 3-19 Average Migration Velocity and Velocity Relative to Average Pore Water for Bacteria from Contrasting Manures

Manure		**Depth (m)**		
		0.3	**0.75**	**1**
Liquid swine	Average bacterial migration velocity (cm/d)	3	9.4	34.8
	Migration velocity relative to average pore water velocity	0.7	3.8	23.0
Solid beef	Average bacterial migration velocity (cm/d)	3.4	6.3	11.9
	Migration velocity relative to average pore water velocity	1.3	3.8	7.1

Soil profile was loam over silt-loam.
Source: after Unc, 1999.

[477] G.E. Jenneman, M.J. McInerney, and R.M. Knapp, 1985, "Microbial penetration through nutrient-saturated Berea sandstone," *Applied Environmental Microbiology*, 50, p. 383.
[478] Bitton and Harvey, 1992.

organisms reaching a water resource. Microorganisms adsorbed to soil particles may survive longer than those in the liquid phase, as organic substrate and nutrients are more readily available to them.[479]

The Ontario Farm Groundwater Quality Survey demonstrates the importance of preferential flow for bacterial transport since bacteria were found in properly maintained drilled wells greater than 30 m deep.[480] Preferential flow can thus facilitate the transport of contaminants to aquifers at depths that might be expected to remain unaffected by surface contaminants. This presents an important concern for predictions of bacterial transport. For example, when flow parameters in the theoretical model described by Corapcioglu and Haridas were taken to the permissible limits, the predicted extent of bacterial transport through unsaturated soil over 2 weeks was 0.2 m.[481] Tamási reported that *E. coli* and *Salmonella typhimurium*, applied in liquid manure, rarely penetrate deeper than 1.6 m in packed columns of either a sand or a garden soil.[482] But Smith et al. observed that *E. coli* penetrated through a column of undisturbed soil to a depth of 0.3 m in 20 minutes.[483] Harvey et al. observed that bacterial-sized microspheres were transported through several metres of aquifer material.[484] Unc estimated the depth of soil necessary to filter out bacteria from manure applied under field conditions.[485] Based on bacterial counts measured at 0.75 m, values ranged from 0.1 m to more than 20 m (figure 3-8), demonstrating the importance of preferential flow paths. The vertical distribution of beneficial microorganisms applied to the soil also depends on preferential flow.[486]

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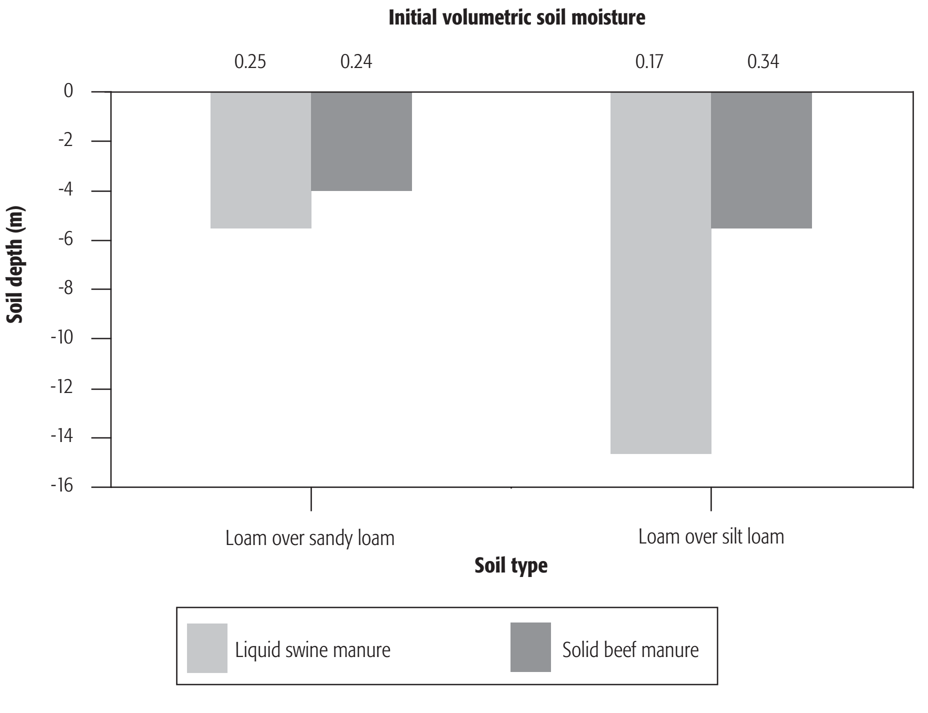
[479] M.D. Sobsey, 1983, "Transport and fate of viruses in soils," *Microbial Health. Considerations of Soil Disposal of Domestic Wastewaters*, L.W. Canter, E.W. Akin, J.F. Kreissl, and J.F. McNabb (eds.), (Cincinnati, OH: U.S. Environmental Protection Agency), p. 175.
[480] Goss, Barry, and Rudolph, 1998.
[481] M.Y. Corapcioglu and A. Haridas, 1985, "Microbial transport in soils and groundwater: A numerical model," *Advances in Water Resource*, 8, p. 188.
[482] G. Tamási, 1981, "Factors influencing the survivial of pathogenic bacteria in soils," *Acta Veterinaria Academiae Scientiarium Hungaricae*, 29, p. 119.
[483] Smith, Unwin, and Williams, 1985.
[484] R.W. Harvey, L.H. George, R.L. Smith, and D.R. Leblanc, 1989, "Transport of microspheres and indigenous bacteria through a sandy aquifer: Results of natural and forced-gradient tracer experiments," *Environmental Science & Technology*, 23, p. 51.
[485] Unc, 1999.
[486] A. Natsch, C. Keel, J. Troxler, M. Zala, N. Von Albertini, and G. Defago, 1996, "Importance of preferential flow and soil management in vertical transport of a biocontrol strain of *Pseudomonas fluorescens* in structured field soil," *Applied and Environmental Microbiology*, 62, p. 33.

3.3.5.5 *Protozoa*

The transport of protozoa has been studied in far less detail than bacterial transport has. The movement of *Cryptosporidium parvum* oocysts through saturated columns of glass spheres, coarse sand, or shale aggregate has been modelled. The oocysts (from dairy calves) did not adhere to sand or glass spheres, moving throughout the system of pores between the particles. The oocysts moved preferentially in the larger pores between shale aggregates. Sand was more effective at removing oocysts than were the other particles, probably by filtration. The authors suggested that their results indicated that significant transport was possible in both surface runoff and with infiltrating water.[487]

Figure 3-8 Variation in the Depth of Soil Required to Filter Bacteria in Manure



Liquid swine and solid beef manure were applied to loam over sandy-loam and loam over silt-loam soils. The drier conditions on the loam/silt-loam soil when liquid manure was applied likely increased preferential flow because of channel formation by shrinkage.
Source: Unc, 1999.

[487] C.F. Brush, W.C. Ghiorse, I.J. Annguish, J.Y. Parlange, and H.G. Grimes, 1999, "Transport of *Cryptosporidium parvum* oocysts through saturated columns," *Journal of Environmental Quality*, 28, p. 809.

3.3.5.6 *Endocrine-disrupting compounds*

If manure containing endocrine-disrupting compounds is left on the soil surface, it can move to surface water in runoff (see section 3.2.8.4). The identification of equol in tile-drainage water is evidence that these compounds can at least leach from soil and move into surface water. Given that similar compounds are not readily identified in the soil,[488] it seems likely that the movement to the tile drains is mediated by preferential flow. Therefore, it is also possible for these compounds to move to groundwater via similar pathways.

3.3.5.7 *Summary*

Only a small part of the nitrogen from manure is likely to be lost in surface runoff from arable fields. More P is likely to be lost in runoff than by leaching. Leaching to groundwater is a significant pathway for NO_3^- loss. Mobility of metals in soil is likely to be increased when they are applied in animal manure. Bacteria can impact surface water through runoff and in tile drainage. They can also be transported to groundwater. The movement through soil of all potential contaminants from manure is enhanced by preferential flow.

3.3.6 Predicting contamination of water resources by components of manure

Many models have been developed to predict the NO_3^- concentration in water leaving the rooting zone of crops and the impact or risk of contamination from agricultural practices.[489] The NLEAP model predicts the risk of groundwater contamination by nitrate for applications of manure.[490] However, predictions of nitrogen mineralization from manure and of gaseous losses lacks validation for Ontario.

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[488] M. Colucci, H. Bork, and E. Topp, 2001, "Persistence of estrogenic hormones in agricultural soils I:17beta-Estradiol and estrone," *Journal of Environmental Quality*, [In Press].
[489] M.J. Shaffer, A.D. Halvorson, and F.J. Pierce, 1991, "Nitrate leaching and economic analysis package NLEAP model description and application," *Managing Nitrogen for Groundwater Quality and Farm Profitability*, R. Follett, D.R. Keeney, and R.M. Curse (eds.), (Madison WI: Soil Science Society of America), p. 85; Ahuja, Barnes, and Rojas, 1993.
[490] Shaffer, Halvorson, and Pierce, 1991.

Although the presence of pathogenic bacteria in both manure and receiving waters is well documented, and the phenomena influencing bacterial transport are known, the actual effect of manure on the quality and quantity of bacterial contamination is less well understood. Aspects of bacterial transport have been studied, but mainly under laboratory conditions. Such experiments have mostly evaluated the effects of various individual factors on the bacterial transport. Thus, while many predictive models for the transport of soluble forms of contaminants have been developed, few models exist that describe bacteria transport. Those that are available are still in the formative phase (e.g., the LEACHB routine of the LEACHM program[491]). No account is taken of the potential effect of the manure on the bacterial transport, despite the fact that manure is one of the major sources of pathogens contaminating groundwater and surface waters. The possibility for preferential flow needs to be included in such models. The microbial model in LEACHB considers microbial dynamics as affected by substrate availability and prey-predator interaction. Bacterial growth and distribution can influence the transport of solutes. The model, however, does not refer to physical movement of bacteria. The only movement between locations is considered in the context of the distribution of available substrates. The model also does not allow for a bacterial population to die. All these characteristics make the model suitable for describing the movement of indigenous soil bacteria that are in a dynamic equilibrium, but not the transport of fecal bacteria introduced in an application of manure.

3.3.6.1 *Summary*

While many models exist to describe nitrate leaching, the concentration of NO_3^- (the important determining factor) is difficult to predict because of the factors that influence the final concentration, such as mineralization of organic nitrogen and the gaseous loss of ammonia and gases such as N_2O. Bacterial transport in the unsaturated zone is poorly described in existing models because they largely ignore the component of movement associated with preferential flow.

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[491] J.L. Hutson and R.J. Wagenet, 1992, *LEACHM – Leaching estimation and chemistry model, Version 3. Research Series No. 92-3* (Ithaca, NY: Dept. of Soil, Crop and Atmospheric Sciences, Cornell University).

3.4 Future Research Needs

This review of manure management practices highlights the significant knowledge gaps that limit our ability to prevent contaminants from manure reaching water resources. Producers recognize the potential benefits of using the crop nutrients in manure, both because it is a means of reducing costs and it contributes toward the sustainable use of resources. Most of the guidance from government and researchers is aimed at conserving nutrients during manure storage and optimizing their availability to crops after field application. It is assumed that this approach will minimize environmental contamination from nitrogen (nitrate, nitrite, ammonia and other N-containing gases) and phosphate. Little attention has been given to developing manure management practices for field application that are specifically designed to deal with pathogens. Nonetheless, there is a Best Management Practice (BMP) to identify the minimum safe distance between a well and the point where manure is spread to minimize contamination by pathogens, and another aimed at preventing liquid manure from flowing directly into a tile drain (see section 2). Environmental aspects of other potential contaminants identified in this section have not been incorporated into recommended manure management practices.

Two reports have made recommendations on manure-related research.[492] Both concentrated on aspects of nutrient management. Researchers have made significant progress toward meeting those recommendations, particularly those that relate to water quality. Based on the limitations presented in this section, however, some recommendations still require a significant research effort to safeguard water resources from contamination by nitrate, phosphate, and organic carbon compounds in manure.

The following research recommendations are related to the availability of crop nutrients in manure and the protection of water resources.

- Establish the relationship between environmentally safe and most profitable rates of manure application to cropland, taking account of the method and timing of applications. This also requires the development of more acceptable manure application methods in conservation tillage systems.[493]

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[492] Miller et al., 1990; M.J. Goss, J.R. Ogilvie, E.G. Beauchamp, D.P. Stonehouse, M.H. Miller, and K. Parris, 1994, *Current State of the Art of Manure/Nutrient Management*, COESA Report No. RES/MAN-001/94 prepared for Research Branch, Agriculture and Agri-Food Canada.
[493] Miller et al., 1990; Goss et al., 1994.

- Complete the means of predicting the composition of the major types of manures, based on feeding regimes, and investigate the long-term effects of feed additives on manure management. This should include studies on the dynamics of carbon compounds from feed and the impacts of different handling systems.[494]

- Investigate and develop the ability to predict the transformations of manure-N during storage (including composting) and following addition to soil to characterize the mineralization, immobilization, and N-gas forming processes that impact on the availability of N to crops and the loss of ammonia and nitrous oxide.[495]

- Leaching of nitrate from grazed pastures and fields receiving regular applications of manure needs to be determined for Ontario conditions.[496]

Further research is also warranted on the amount of metals being applied to Ontario fields, especially in swine manure. As the use of copper in feed is related to perceived reductions in the use of antibiotics in animal husbandry, research efforts need to be integrated in these areas.

Continued research on manure management in relation to pathogens is clearly required. From the perspective of animal husbandry, clear knowledge gaps surround the shedding of *E. coli* O157:H7, particularly about seasonality, the influence of diet, and dietary changes. Information on the shedding of other pathogens is also not well documented. Vaccines to prevent the colonization of cattle by *E. coli* O157:H7 need to be developed.

The link between the different serotypes of several pathogens found in animals and the incidence of disease in humans needs to be clarified.

Economically viable treatments of manure in storage, which can effectively conserve nutrients and reduce the loading of pathogens, need to be developed. These must be considered in conjunction with odour control.

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[494] Goss et al., 1994.
[495] Miller et al., 1990; Goss et al., 1994.
[496] Goss et al., 1994.

In Ontario, few practising agricultural engineers work on machinery, particularly that for land application of manure. However, improved application equipment is needed to ensure that the appropriate rates of manure are applied to meet crop requirements indicated by nutrient management planning, while protecting water resources from contamination. There is a specific need for manure injectors with more rapid throughput capacity.

Application techniques need to be developed to reduce the likelihood of preferential flow when liquid manure is applied. This should be coupled with the development and evaluation of predictive models for the transport to groundwater of dissolved and particulate contaminants, such as bacteria and other pathogens, that take hydrological factors into account.

The fate of organic compounds, such as antibiotics and natural estrogens, needs to be determined quantitatively, including the possibilities of reducing the content in manure during storage as well as considering transport to water resources once manure has been applied to the land. Application techniques that discourage preferential flow would probably reduce the likelihood of groundwater contamination.

Few BMPs for manure management have been evaluated under commercial farming. These activities need to be accelerated to ensure that the best advice is available to producers.

3.4.1 Summary

There are significant needs for research in the field of manure management if water resources are to be protected from contaminants originating in manure. These needs cover aspects of feeding regimes, animal husbandry, manure treatment, and field application. They include both basic and applied research and machinery development. The contaminants to be considered include nitrate, phosphorus, metals, pathogens, antibiotics, and natural endocrine-disrupting compounds.

4 Manure Production in Ontario

4.1 Background

This section provides basic information on the distribution of livestock farms in Ontario, the species of animals involved, and the amounts of manure produced. It focuses on the likely changes in manure production over the next 5–10 years within the province. When looking at manure production in the future, many factors have been taken into consideration, including:

- market trends in both the domestic and export markets;
- the possible impact of new manure-management technologies;
- international trade agreements, e.g., the World Trade Organization which has as its long-term goal tariff reductions and ensuring fair trading practices; and
- the level of competition from other provinces and the United States.

4.2 Objectives

The overall objective of this section is to benchmark manure production levels within the province and to forecast growth for the major livestock industries in Ontario by geographic region. The specific objectives are:

- to describe Ontario's livestock industries in terms of farm numbers, amount of crop land, manure spreading practices, and economic scale.

- using Statistics Canada census data, to catalogue historical and current animal numbers at both a county/municipality and township level for the species of beef, dairy, swine, turkey, chicken, and laying hens.

- based on the animal numbers, to calculate historical and existing manure production at both the county/municipality and township level.

- using the manure production calculations, to determine the total amount of nitrogen (N), phosphorus (P), and potassium (K) in livestock manure.

- to develop livestock growth predictions for the major livestock industries of beef, dairy, swine, turkey, chicken, and laying hens.

- using this information, to forecast the amount of manure likely to be produced in the next 5–10 years.

4.3 Methodology

The livestock and poultry inventory numbers were obtained from Statistics Canada's census years of 1986, 1991, and 1996.[497] Data were also obtained from Statistics Canada to graph historical cattle and pig inventories. Breakdowns by animal size for cattle and swine were obtained from Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) statistics.[498] The OMAFRA numbers for swine were identical to the Statistics Canada numbers. Although the beef numbers differed slightly for July 1999 between Statistics Canada and OMAFRA, the OMAFRA numbers were used for determining inventory percentages. This method provided a reasonable and recent allocation of animal sizes for the purpose of calculating manure production. The OMAFRA data were not used to generate animal number forecasts.

To calculate the number of animals per livestock unit, we used the guidelines set by OMAFRA for calculating minimum distance separations.[499] A livestock unit is defined as the "equivalent value for various types of animals including poultry, based on manure production and production cycles."[500] Minimum distance separation calculations are used to determine the recommended distance between a livestock operation and another land use, such as a neighbour.[501] This distance is influenced by the type and amount of livestock in the facility and the type of manure handling system. The intent of minimum distance separations is to reduce the number of complaints related to odour and land use.

Appendix 4-1 shows these calculations by livestock type. Census and MDS II categories for calculating livestock units are not always the same. In these cases,

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[497] Canada, Statistics Canada, Agriculture Division, 1987, *Census of Canada, 1986 – Agriculture – Ontario* (Ottawa: StatsCan); Canada, Statistics Canada, Agriculture Division, 1992a, *Agricultural Profile of Ontario, Part 1: 1991 Census* (Ottawa: StatsCan); Canada, Statistics Canada, Agriculture Division, 1997, *Agricultural Profile of Ontario: 1996 Census* (Ottawa: StatsCan).

[498] Ontario, Ministry of Agriculture, Food and Rural Affairs, 1999b, *Number of Cattle, Ontario* [by County], <www.gov.on.ca/OMAFRA/english/stats/livestock/index.html>; Ontario, Ministry of Agriculture, Food and Rural Affairs, 1999c, *Number of Pigs, Ontario* [by County], <www.gov.on.ca/OMAFRA/english/stats/livestock/index.html>.

[499] OMAFRA, 1995b; OMAFRA, 1995c.

[500] OMAFRA, 1995c.

[501] Ibid.

the census category was matched to the MDS II category that would result in a maximum number of livestock units. For example, a census category called "all other pigs" includes pigs from birth to market weight, excluding sows and boars. MDS II categories include weaner pigs (20 pigs/LU) and feeder pigs (4 pigs/LU). In order to estimate manure production at the upper end, it was assumed that the category "all other pigs" are entirely feeder pigs, with 4 animals per livestock unit. While this practice likely overstated the actual number of livestock units for each livestock type, it is preferable to underestimating. This approach was also used to calculate manure production, as it provides information on the maximum amount of manure produced.

To predict livestock numbers and manure production in the future, we sought input from various producer organizations. This information is summarized in section 4.5 and the questionnaire used is found in appendix 4-2. Each commodity group was asked the same questions, which focused on livestock growth predictions and new manure-management technologies. Other methods used to predict future animal numbers included baseline projections supplied by Agriculture and Agri-Food Canada, input from industry analysts, and computer-generated linear-regression trendlines based on historical livestock numbers.

There are several limitations to the manure projections presented here.

- Manure estimates are based on the average daily volumes of fresh material excreted by the various animal groupings reported by OMAFRA (see appendix 4-3). No allowance has been made in the manure calculation for water used in washing, frequently used in the swine and dairy industries. Typically, stored swine manure is more than 95% water. As well, no allowance has been made for straw, shavings, or other bedding material which is used extensively by some livestock production systems (e.g., dairy). While straw and shavings do not increase the concentration of manure, they do increase the volume to be utilized.

- The manure calculations fail to include manure generated from sheep, horses, and nontraditional livestock such as deer, elk, bison, and llamas. This exclusion may mean that the total amount of manure produced is somewhat underestimated.

- The volume of manure generated does not take rainwater into account. Rainwater can add a significant volume if the manure is stored outside in an uncovered tank. Recall that Ontario receives about 750–900 mm of rainfall annually (the 30-year average for Ridgetown College, University of Guelph, for the eight-month period between April 1 and November 30 is 645.4 mm).

- Many areas of the province have been amalgamated in recent years. However, most of the census data at the township level used in this report was collected before amalgamation and does not reflect recent municipal restructuring.

- Livestock numbers are not based on an average of beginning and ending animal numbers, but rather the number of animals on hand at given points in time (e.g., census or Statistics Canada inventory dates). This assumes a consistent number of animals in the province and does not allow for fluctuations in production. Manure production (litres/day/animal) is based on these actual inventory levels on each date and is multiplied by 365 days to provide an annual value.

- The most recent census in 2001 has not been analyzed, so recent increases or declines in animal numbers at the county/municipality and township level are not known.

Occasionally, animal numbers in a provincially designated region may not equal the total provided for that particular region. This is due to rounding errors in the calculations and because some data were not included at the township (or even county/municipality) level due to confidentiality concerns.

4.4 Results

4.4.1 Farm Structure

Table 4-1, which depicts Ontario farms by revenue class for 1997, shows three main trends. Firstly, the dependence of the farm family on off-farm income is largely related to farm revenue. In 1997 for example, farm income contributed negatively to the total family income in the $10,000 to $24,999 farm revenue class. In Canada as a whole, 68% of dairy farms depend entirely on farm income. Exclusive dependence on farm income for other farm types are: hog: 51%, poultry and egg: 49%, and beef cattle: 12%.

The second trend seen is that the bulk of Ontario's agricultural sales comes from relatively few farms. Only about 20% of the farms were in the top two revenue classes ($250,000 and up) but those farms produced some 67% of all agricultural sales. Although important in terms of numbers, farms with revenues below $50,000 (38.6% of all farms in 1997) generally contribute very little to overall production (a total of 5.2%).

Thirdly, it appears that high-revenue farms require significant capital investment. Farms in the top revenue class had average net worths of $1,812,608 while those in the lowest class had net worths of $313,718. These high-revenue farms are also investing for the future, with an average net investment of 5.4%, while low-revenue farms invested only 1.5% of assets.

In summary, a relatively small number (20.2%) of farms produce the majority (67.1%) of total Ontario agricultural sales. Operators of these high-revenue farms are committed to commodity-based production and invest in the future of their farming enterprises.

Table 4-1 Profile of Ontario Farms by Revenue Class, 1997

Gross Revenue Class	Number of Farms	Average Number of Operators	Average Net Operating Income ($)	Average Off-Farm Income per Farm*($)	Farms (%)	Production (%)	Net Worth per Farm ($)	Net Investments as % of Assets
$10,000 to $24,999	7,632	1.5	(344)	45,136	18.8	1.6	313,718	1.5
$25,000 to $49,999	8,055	1.5	1,716	34,847	19.8	3.6	370,554	3.5
$50,000 to $99,999	6,810	1.5	12,900	35,059	16.8	6.2	516,952	2.9
$100,000 to $249,999	9,924	1.7	32,384	18,374	24.4	21.5	784,531	3.2
$250,000 to $499,999	5,073	1.9	60,060	16,168	12.5	23.0	1,144,058	4.7
$500,000 and over	3,121	2.2	225,387	19,733	7.7	44.1	1,812,608	5.4
All Classes	40,616	1.7	35,174	29,296	100.0	100.0	693,005	3.9

* Off-farm income was reported for the operator (and his family) responding to the survey.

Source: Canada, Statistics Canada, Agriculture, 1997.

4.4.2 Livestock Farm Numbers

In 1996, Ontario had 28,885 livestock farms (dairy, beef, hog, poultry/egg, and livestock combinations).[502] The bulk (60%) of these farms are located in the two regions of Western and Southern Ontario. Northern Ontario has the fewest livestock farms (1,309, less than 5%). The average number of livestock farms per county/municipality in the regions of Southern, Western, Central, and Eastern Ontario was 726. Table 4-2 shows a regional breakdown of livestock farms. For a breakdown by county/municipality, see appendix 4-4.

Map 4-1 shows livestock farm numbers by county/municipality, based on 1996 census data. The five counties with the most livestock farms are Bruce, Grey, Huron, Perth, and Wellington. Those with the lowest number of livestock farms are in the extreme southern part of the province (Essex, Kent, and Elgin), the Golden Horseshoe, and more northerly regions such as Muskoka District. We do not consider the Northern region because of the sparse livestock numbers.

4.4.3 Historical Livestock Numbers

Figure 4-1 shows the historical livestock numbers in Ontario between July 1, 1976 and July 1, 2000. Statistics Canada Livestock Inventories are taken either quarterly or biannually. (No inventory numbers are available for poultry.) The

Table 4-2 Total Number of Livestock Farms by Region

Ontario Region	Total Number of Livestock Farms
Southern	5,329
Western	11,910
Central	4,761
Eastern	5,576
Northern	1,309
Total Ontario	**28,885**

Source: Canada, Statistics Canada, Agriculture, 1997.

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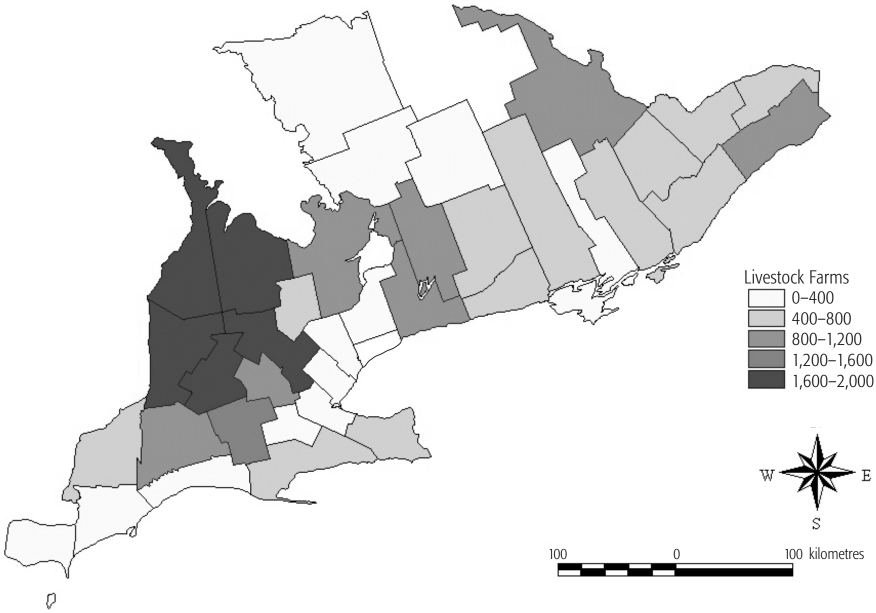
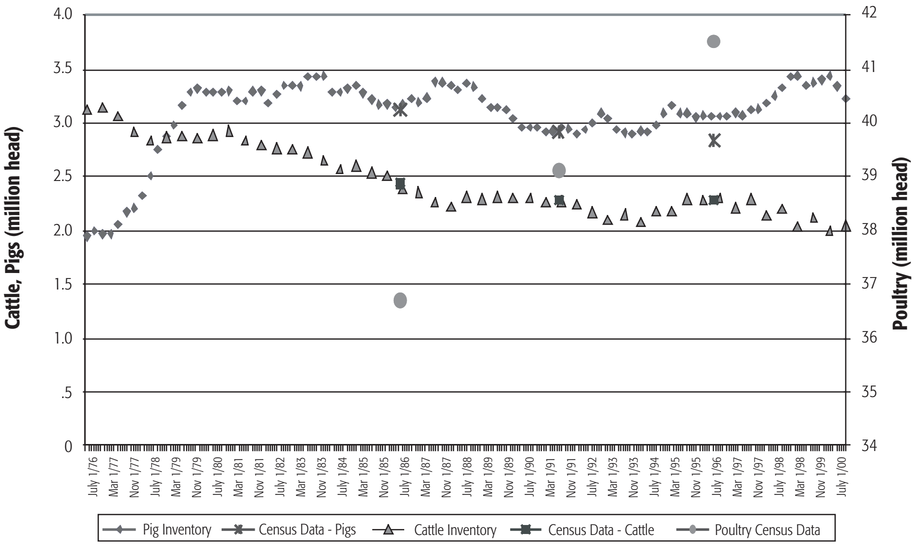
[502] Canada, Statistics Canada, Agriculture, 1997.

Map 4-1 Total Number of Livestock Farms by County/Municipality, 1996



Source: Canada, Statistics Canada, Agriculture, 1997.

Figure 4-1 Historical Inventory of Cattle, Pigs, and Poultry in Ontario from July 1, 1976 to July 1, 2000



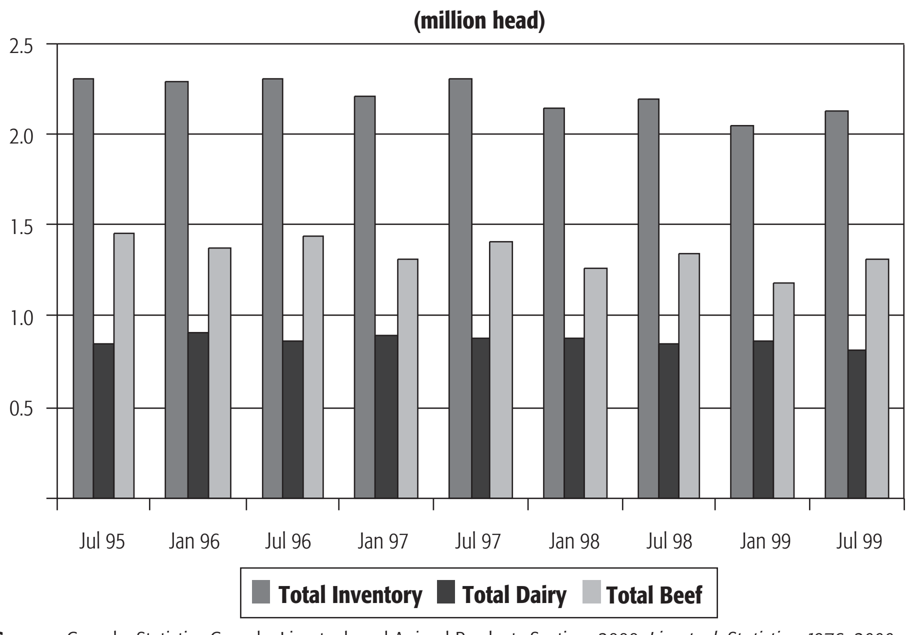
Numbers are expressed in million head. Beef and dairy cattle are combined. Both Statistics Canada census and inventory data are used.

alignment between the Livestock Inventory numbers and the five-year census data for cattle and pigs lends credibility to the projected manure production calculations as both sets of data are used in forecasting inventory levels for cattle and pigs. The Inventory shows 62% beef cattle and 38% dairy cattle.

The cattle inventory has shown a downward trend over the past 24 years, from a high of 3.1 million head in 1976 to 2 million in the year 2000. This 35% decline plays an important role in the amount of manure produced annually in the province. The 24-year trendline for pigs is relatively flat, with inventory fluctuating between 3 and 3.5 million head. Poultry has shown some growth, with a low of 37 million in 1986 expanding to 41.5 million in 1996, a 12% increase.

Figure 4-2 provides a more recent snapshot of beef and dairy cattle numbers from Statistics Canada, Livestock Division. Between July 1995 and July 1999, the dairy inventory has remained relatively constant but beef numbers have increased and decreased yearly, with total inventory numbers trending downward. The dairy cattle inventory ranged between 911,000 (July 1996) and 811,000 head (July 1999). The beef cattle inventory ranged between 1.4 million (July 1995) and 1.2 million head (January 1999). Probable reasons

Figure 4-2 Ontario Beef and Dairy Inventory Values



Source: Canada, Statistics Canada, Livestock and Animal Products Section, 2000, *Livestock Statistics, 1976–2000* (Ottawa: StatsCan).

why Ontario's beef numbers have declined include: strong competition from Western Canada, natural fluctuations caused when farmers retire, and poor profitability caused by rising costs of production. Between 1995 and 1999, the average beef farm had about 60 head while the average dairy farm had close to 100 head.

4.4.4 Livestock Units and Manure Production per County/Municipality

Table 4-3 shows the ranking of the top ten counties/municipalities in terms of manure production in 1996. These county/municipality rankings changed only slightly in the three census years. Huron County was ranked first in 1986 and second in 1996. Other areas changing ranking between 1986 and 1996 were: Middlesex (moved from 5th to 6th), Waterloo (8th to 7th), Bruce (6th to 5th), and Grey (7th to 8th).

Most counties in Ontario experienced a decline in manure production between 1986 and both 1991 and 1996. Increases did occur in Kent (10.3% in 1991,

Table 4-3 Livestock Units and Top-ten Counties/Municipalities in Terms of Manure Production, 1996

Area	Total Livestock Units: 1996 (000s)	Total Manure (million L/yr, 1996)	% Change 1991 Versus 1986	% Change 1996 Versus 1986
Perth	206	2678	2.1	6.8
Huron	212	2655	–2.5	4.1
Wellington	164	2010	–3.2	–4.2
Oxford	142	1848	–10.8	–6.7
Bruce	146	1781	–9.1	–7.0
Middlesex	131	1596	–6.1	–15.9
Waterloo Region	118	1521	–1.0	–5.3
Grey	125	1399	–8.3	–10.1
Lambton	95	1204	–9.4	–9.0
Simcoe	86	1012	–17.5	–18.6

Source: Canada, Statistics Canada, Agriculture, 1997.

35.4% in 1996); Perth (2.1% in 1991, 6.8% in 1996), Renfrew (1.8% in 1991, 6.6% in 1996), and Huron (4.1% in 1996). For the province as a whole, manure production between 1986 and 1991 decreased by 5.9% and between 1986 and 1996 by 7.5%. Eight counties or municipalities showed manure production decreases of over 20% between 1986 and 1996. Listed in order from the largest decrease to smallest, they are: Halton, Muskoka District, York, Haliburton, Essex, Dufferin, Prince Edward, and Niagara. The decreases in manure production tended to be more dramatic for the 10-year period of 1986 to 1996 than for the five-year period of 1986 to 1991.

It can also be seen from table 4-3 that the Western and Southern regions of Ontario have by far the most livestock units and hence the most manure production. For a complete listing of animal numbers, livestock units, manure production, and percent change in manure production for all 39 Ontario counties/municipalities, please see appendix 4-5.

An interesting trend is the changes in the numbers of livestock units between the three species: poultry, cattle, and swine. This, of course, affects the amounts of manure produced. In Bruce County, for example, manure production from swine and cattle has decreased (by 33% and 1% respectively) while poultry manure has increased some 61% between 1986 and 1996. In Huron and Perth Counties, cattle manure production has decreased while swine and poultry manure has increased. The Niagara Region shows manure production declining in all three species, with swine decreasing some 45% over the 10-year period. Wellington County has seen its poultry and cattle manure production increase (by 23% and 1% respectively), while swine manure production decreased (14%).

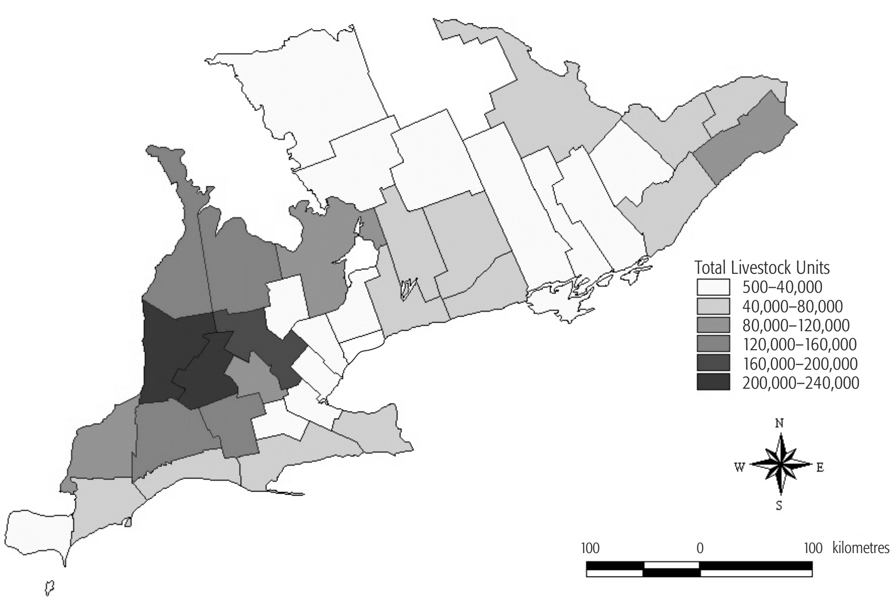
Map 4-2 summarizes the total number of livestock units by county/municipality in 1996. The map illustrates table 4-3, showing that Huron, Perth and Wellington have the greatest number of livestock animal units. As one would expect, few livestock units are shown in the County of Essex, the Golden Horseshoe, parts of the Eastern region, and more northerly parts of southern Ontario. Map 4-3 depicts total manure production by county/municipality for 1996. Not surprisingly, the distribution of manure production is very similar to the distribution of livestock units seen in Map 4-2.

Table 4-4 summarizes animal units and manure production at the township level in six counties/municipalities: Niagara, Oxford, Wellington, Perth, Huron, and Bruce. The counties/municipalities were selected because of their traditionally high livestock numbers. Only the two townships in each area with the greatest manure production are reported here. At the township level, the changes in manure production tend to be more dramatic. For example, Grey Township in Huron County saw manure production increase by 12.1% between 1986 and 1991, while the 10-year growth between 1986 and 1996 was a huge 75.3%.

Of these six counties/municipalities, the townships in the Niagara region showed the largest reduction in manure production. It is worth noting that even within counties such as Huron and Perth, not all townships experienced increases in manure production (see appendix 4-6). For example, manure production in Blanshard Township in Perth County decreased by 34% over the 10-year study period. For a complete breakdown of manure production in the six counties/ municipalities at the township level, see appendix 4-6.

When looking at manure production by species type at the township level, some caution must be exercised. It is possible to have rapid manure production growth on a percentage basis but still have a relatively limited expansion in livestock units. For example, Kincardine township's poultry units grew from 33 in 1986 to 528 in 1996, small by comparison with other townships, thus

Map 4-2 Total Number of Livestock Units by County/Municipality, 1996



manure production increased by close to 1,363%. Still these percent changes can be used to see general trends. By and large, the swine, poultry, and cattle livestock units in most townships in the Niagara region have declined while townships in the heavy livestock counties of Huron and Perth have increased their swine and poultry livestock units.

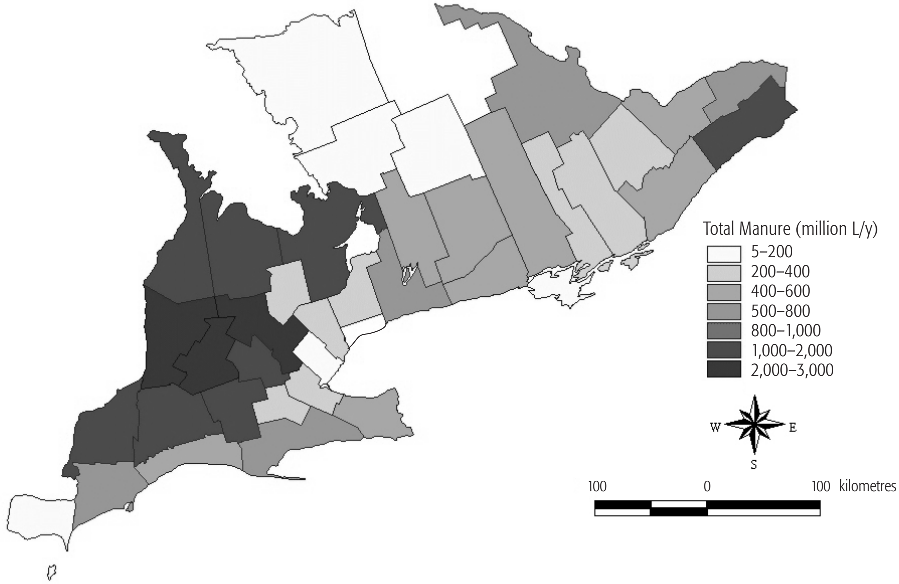
Maps 4-4, 4-5, 4-6, and 4-7 show 1996 livestock units and manure production at the township level for Huron County and Niagara Region. These two areas were selected because they represent two different geographic regions of the province. No obvious trends can be seen about locations of the different species: one township doesn't have all the pigs while others have all the cattle. Perhaps

Table 4-4 Livestock Units and Manure Production by Township, 1996

Township	Total Livestock Units (000s)	Total Manure (million L/yr)	Change 1991 vs 1986	Change 1996 vs 1986
Niagara				
West Lincoln	25.1	244.9	-20%	-23%
Wainfleet	6.9	79.8	-17%	-21%
Oxford				
Zorra	39.9	539.3	-5%	-3%
East Zorra-Tavistock	28.4	381.4	-9%	5%
Wellington				
Peel	42.3	545.6	-1%	<1%
Maryborough	26.3	309.3	-9%	1%
Perth				
Elma	28.5	354.6	-9%	-5%
Ellice	25.7	341.4	13%	30%
Huron				
Grey	30.1	402.7	12%	75%
Howick	24.2	315.4	2%	12%
Bruce				
Carrick	17.5	223.0	-6%	-8%
Elderslie	16.3	213.8	-12%	12%

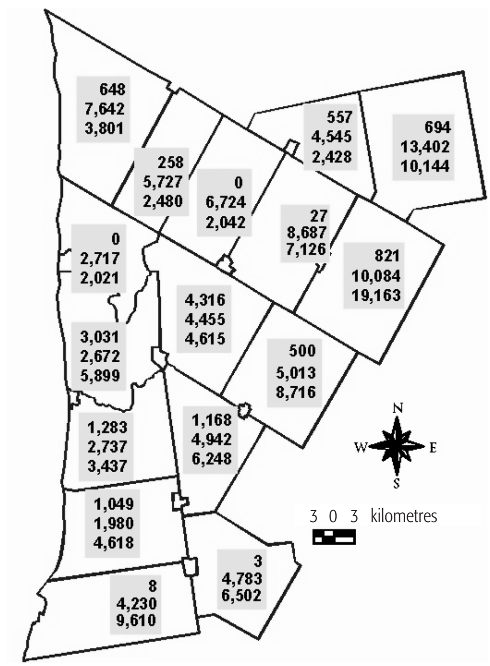
Source: Canada, Statistics Canada, Agriculture, 1997.

Map 4-3 Total Manure Production by County/Municipality, 1996



Map 4-4 Huron County: Livestock Units by Township, 1996

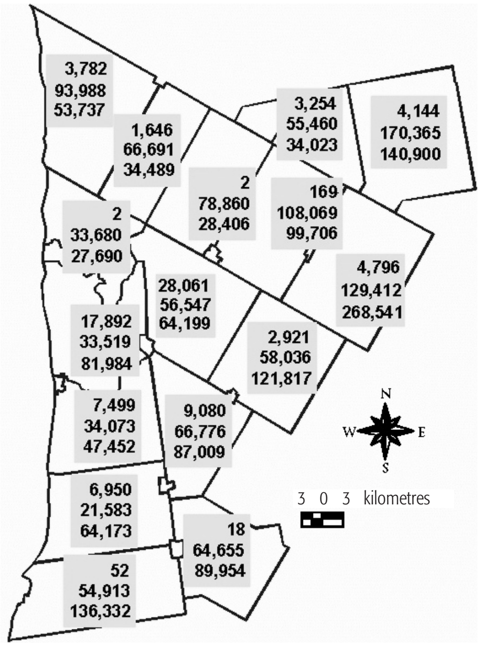
22,695 Poultry
90,340 Cattle
98,851 Swine



Note: Township animal numbers may not equal the total provided for the county/municipality due to rounding error and confidentiality concerns.

Map 4-5 Huron County: Manure Production (000 L/yr) by Township, 1996

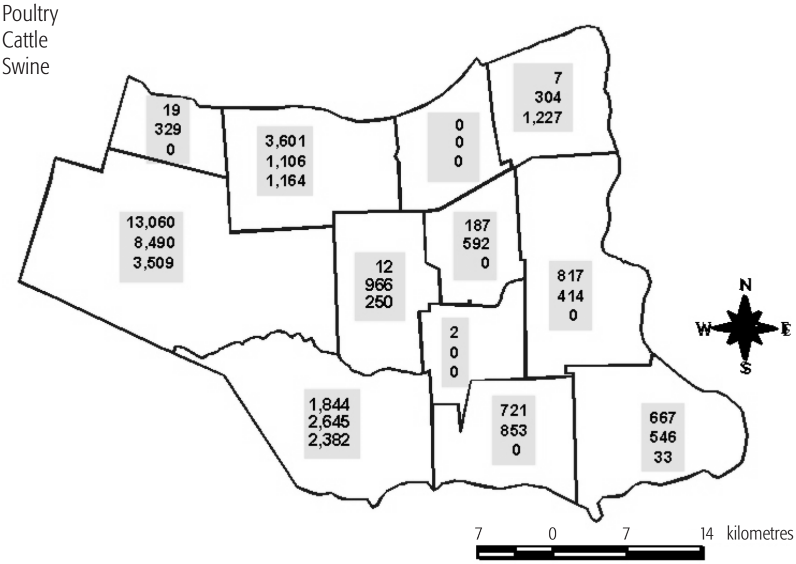
148,244 Poultry
1,126,736 Cattle
1,380,411 Swine



Note: Township animal numbers may not equal the total provided for the county/municipality due to rounding error and confidentiality concerns.

Map 4-6 Niagara Region: Livestock Units by Township, 1996

36,816 Poultry
16.406 Cattle
9,315 Swine



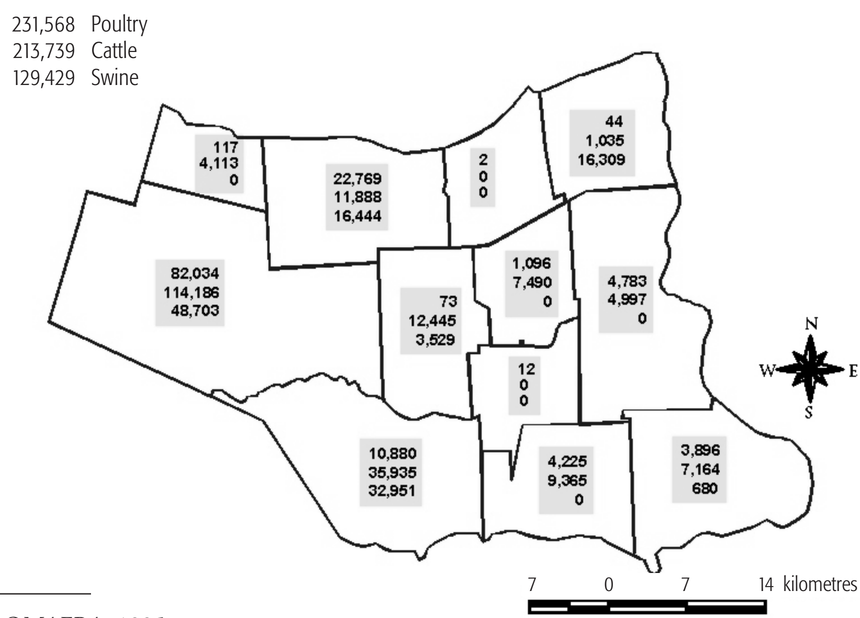
Note: Township animal numbers may not equal total provided for the county/municipality due to rounding error and confidentiality concerns.

one exception to this statement is the low poultry numbers in the northern townships in Huron County. Niagara Region livestock units and manure production are lowest in townships along Lake Ontario (a fruit farming area) and those surrounding the Welland Canal (a housing area).

Table 4-5 shows the amounts of nitrogen, phosphorus, and potassium excreted in livestock manures at the county/municipality level. The data are calculated from the information in appendix 4-5 and N, P, and K values in appendix 4-3.[503] For the province as a whole, the amount of nitrogen excreted decreased by 5.6% between 1986 and 1991 and 6.7% between 1986 and 1996. Phosphorus and potassium levels also decreased over both the 5- and 10-year periods: 5.5% and 6.2% for phosphorus and 6.6% and 8.2% for potassium. The decreases in these nutrient amounts are not surprising. As was mentioned previously, manure production decreased by 7.5% between 1986 and 1996.

Table 4-5 shows that the quantities of nitrogen produced decreased in all counties except for Perth and Huron. These results track well with the previous tables which showed manure production levels decreasing in most counties/ municipalities. The county/municipality with the largest increase in nitrogen

Map 4-7 Niagara Region: Manure Production (000 L/yr) by Township, 1996



[503] OMAFRA, 1995c.

was Kent with 28.2% (over 10 years) (with a 35% increase in manure production) while Halton had the largest decline at 40.3% (with a 42% reduction in manure) (see appendices 4-5 and 4-7). Maps 4.8 and 4.9 display nitrogen and phosphorus levels by county/municipality for 1996.

On a regional basis, nitrogen excretion in manure declined in both Southern and Western regions 1986 and 1996 (6.8% and 4.0% respectively). These two regions account for 70% of Ontario's livestock units and hence, manure production.

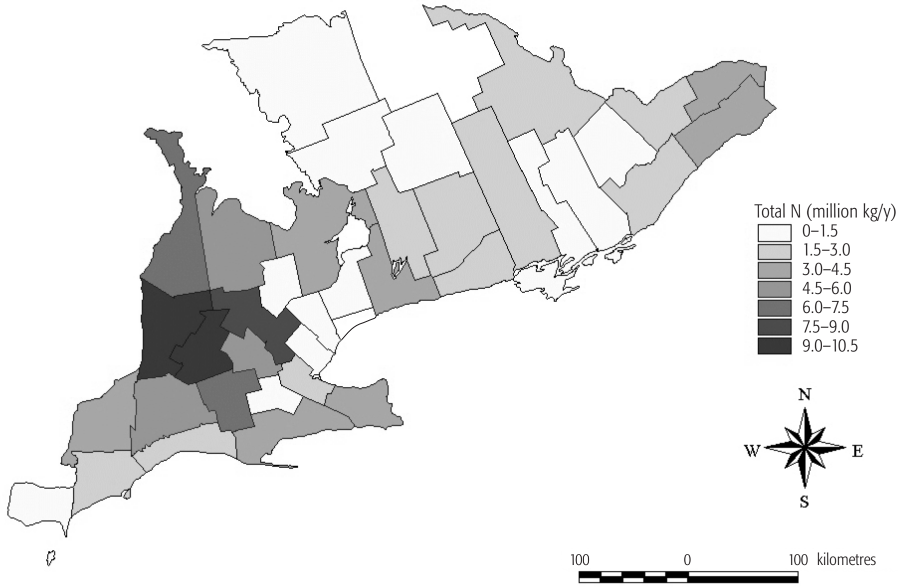
Table 4-6 shows the nitrogen, phosphorus, and potassium amounts excreted annually in livestock manure in 1986 and 1996 for two townships in each of the six counties/municipalities listed earlier. Of the 71 townships in these counties/municipalities, 46 experienced a decrease in nitrogen excretion between 1986 and 1996 while 25 had an increase. Niagara Region had the most townships showing a decrease (10 of 12 townships) while Perth County had the fewest townships with a decrease (only 4 of 11). As one would expect, urban townships showed significant nitrogen declines (e.g., St. Catharines, 98.5% and Guelph,

Table 4-5 Nitrogen, Phosphorus, and Potassium Levels Excreted in Manure in 1986 and 1996 in the Top-ten Counties/ Municipalities (in million kg/yr)

Area	1986 N	1986 P	1986 K	1996 N	1996 P	1996 K	% Change in N
				million kg/yr			
Perth	8.8	4.5	7.3	9.3	4.9	7.2	5%
Huron	9.4	4.8	7.9	9.8	5.0	7.8	5%
Wellington	7.9	4.0	6.9	7.8	3.9	6.8	–2%
Oxford	7.2	3.7	6.3	6.5	3.3	5.7	–9%
Bruce	7.4	3.6	8.1	7.0	3.4	7.8	–5%
Middlesex	7.0	3.7	5.9	5.8	3.1	4.7	–17%
Waterloo	5.9	3.1	4.9	5.7	2.9	4.8	–5%
Grey	6.0	2.9	6.4	5.6	2.8	6.1	–7%
Lambton	4.5	2.4	3.4	4.1	2.2	3.0	–9%
Simcoe	4.7	2.3	5.0	3.8	1.8	4.0	–21%

Source: Canada, Statistics Canada, Agriculture, 1997.

Map 4-8 Total Nitrogen by County/Municipality, 1996



Map 4-9 Total Phosphorus by County/Municipality, 1996